https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Limiting global warming to 1.5°C minimises projected global increases in fire weather days, but adaptation to new fire regimes is still needed

Inika Taylor[1], Douglas I. Kelley[3], Camilla Mathison[1], Karina E. Williams[1,2], Andrew J Hartley[1], Richard A. Betts[1,2], Chantelle Burton[1]

[1] Met Office, Fitzroy Road, Exeter. EX1 3PB UK
[2] Global Systems Institute, University of Exeter, Exeter EX4 4QE UK
[3] UK Centre for Ecology and Hydrology, Wallingford. OX10 8BB UK
Corresponding author: inika.taylor@metoffice.gov.uk, doukel@ceh.ac.uk

Abstract

Understanding future shifts in fire weather risk, including peak season, transitional and off-season, will be crucial for reshaping fire preparation and management in order to adapt to climate change. This study explores future climate-driven projections of fire weather using the McArthur Forest Fire Danger Index (FFDI) across three Global Warming Levels (GWLs) with two future emissions scenarios—1.5°C, 2.0°C under both RCP2.6 and RCP8.5, and 4.0°C under RCP8.5. Using a large, perturbed physics ensemble, we assess uncertainty in fire weather projections globally and for three regions: Australia, Brazil, and the USA. In addition to season length and peak FFDI, we evaluate transitions in meteorological fire danger periods and shifts in low-fire weather windows to inform fire management throughout the annual cycle. We project a global rise in fire weather days and severity at all GWLs, with the largest increases in Australia, followed by Brazil and the USA. At 1.5°C, the area exposed to Very High fire weather (FFDI ≥ 24) expands by 31% (25%–36%) relative to a baseline of 1986-2005. Higher GWLs drive further increases, with more than a threefold rise in Very High fire weather days from 2.0°C to 4.0°C, emphasising the mitigation benefits of limiting global warming to well below 2.0°C as intended by the Paris Agreement. The transition from High to Very High, a proxy for the start of the fire season, advances, by 9–12 days in Australia, 16–22 days in Brazil, and 8–24 days in the USA. Despite these changes, low-fire windows persist, providing crucial opportunities for out-of-season preparation such as controlled burns. Our findings highlight the need for both

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

emissions reductions and adaptive strategies, including accounting for changes in out-of-season fire risks when employing management techniques that rely on pre-fire season preparations.

1 Introduction

Wildfires, defined as unusual or extraordinary free-burning vegetation events, can be destructive to both human society and ecosystems (UNEP et al., 2022). The impacts of wildfires are experienced over a range of timescales. The immediate consequences include loss of life, wildlife, habitat and crops, and destruction of property and infrastructure. The longer-term impacts include environmental damage, reduced air quality contributing to health effects, mental ill health and decreased well-being, economic damage and increased greenhouse gas emissions (Head et al., 2014; Sharples et al., 2016). Fire weather extremes are already more frequent and intense (Dowdy, 2018; Head et al., 2014), and wildfire events are increasing (Jones et al., 2022; UNEP et al., 2022), with recent wildfires providing a glimpse of the devastation that a future fire increase could bring (Jones et al., 2024).

The recent events with the highest associated cost have tended to occur in vegetated areas at the urban/wildland interface that experience drought and/or extreme heat conditions, often associated with fire risk. The Black Summer fires of 2019/2020 in Eastern Australia, for example, were unprecedented in recorded history (Boer et al., 2020), resulting in the loss of at least 34 lives, almost 6000 buildings, hazardous air quality levels and an estimated loss of up to 1.5 billion wild animals (van Oldenborgh et al., 2020; Ward et al., 2020). This event highlights the far-reaching impacts of a wildfire season that was longer than normal, more widespread and reached into areas that do not historically burn (van Oldenborgh et al., 2020). The western USA has also seen a series of recent extreme wildfire events (Higuera and Abatzoglou, 2021), and the unprecedented fires Canada experienced in 2023 saw over 150,000 km² burned, prompting evacuations of 232,000 people and poor air quality across North America (Jain et al., 2024; Jones et al., 2024). Both events were, again, characterised by a shift in fire season alongside an increase in extreme fire behaviour. Much of the forested areas in South America have also seen increases in burning (Ferreira Barbosa et al., 2021; Kelley et al., 2021; Silveira et al., 2020), with widespread fires in northwestern South America in 2023/2024 including parts of Amazonia (Mataveli et al., 2024) largely driven by drier weather conditions and seasonality alongside changes in land use (Jones et al., 2024).

A recent assessment of fire risk due to climate change found that the frequency and severity of fire weather have increased globally, along with an increase in High fire weather season length (Jones et al., 2022; UNEP et al., 2022), particularly in areas where we have seen recent extreme events and seasons (Jones et al., 2024). Climate change's influence over fire's and fire weather is beginning to emerge from natural variability in some regions, including Amazonia and the western USA (Abatzoglou et al., 2019; Abatzoglou and Williams, 2016; Jolly et al., 2015; Kelley et al., 2019; Williams et al., 2019). Even in other regions, such as Australia, where the climate change signal is more difficult to isolate from natural variability (Udy et al., 2024), attribution studies are finding that temperature

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

increases have resulted in at least a 30% increase since 1979 in severe fire weather over the region impacted by the 2019/20 fires (van Oldenborgh et al., 2020).

These destructive wildfires are set to continue, with UNEP et al. (2022) estimating an 8-14% worldwide increase in extreme fire events in the next 10 years and 31-57% by 2100. Southeast Australia, Southern Amazon, and, under higher emissions, Western USA is projected to see significantly more than average increases. These projections include substantial rises even with efforts to cut emissions to limit global warming to 1.5°C above pre-industrial levels, with global impacts on forest cover and carbon sequestration occurring from as early as 1.0-1.3°C (Burton et al., 2024b) - i.e., already (Betts et al., 2023). The Paris Agreement of the United Nations Framework Convention on Climate Change aims to keep the global average temperature rise to well below 2.0°C, aiming for 1.5°C above pre-industrial temperatures (UNFCCC, 2015). However, despite global commitments to reduce emissions, current trends suggest that limiting warming to 1.5°C will be exceedingly challenging, and many regions are already experiencing climate impacts at lower levels of warming. Exceeding these thresholds is expected to bring more frequent and severe wildfire events, underscoring the need for adaptive strategies in fire management, even in the face of efforts to mitigate climate change.

Despite this threat, there has been little progress linking climate, ecological, and fire management research (Hamilton et al., 2024). This lack of progress has been identified as the biggest bottleneck for developing effective and future-proof fire management plans (Jones et al., 2024; UNEP et al., 2022). With an increasing emphasis on preparation for fire seasons rather than solely focusing on fire suppression during the season itself (UNEP et al. 2022), it is particularly important to gather evidence on how fire seasons may shift or change in duration and the implications this has for fire risks during the preparatory periods, outside of the current fire season. A crucial tool to bridge this gap is the combined use of future climate projections in conjunction with fire weather indices. Several factors, including meteorological conditions, fuel availability and moisture content, topography, human land use, and landscape/fire management, all influence the level of danger and severity of fires (Yeo et al., 2015). Climate change affects both meteorological conditions and suitable climate conditions for fuel (Flannigan et al., 2016). The weather and longer-term climate conditions that a fire needs to burn if ignited with available fuel are often referred to as "fire weather". Fire weather indices, such as the McArthur Forest Fire Danger Index (FFDI) (Noble et al., 1980), combine meteorological conditions, including high temperature, dry air (low relative humidity), dry fuel and ground (due to lack of rain and low soil moisture), and wind, to provide an index that can quantify the direct meteorological impact, including from climate change, on fire risk. Indices such as the FFDI are particularly useful in ecosystems with abundant fuel, such as temperate and tropical forests, where meteorological factors, rather than fuel availability, drive fire occurrence and severity, particularly for the more extreme fires (Jolly et al., 2015; Kelley and Harrison, 2014). In these regions, fire indices can forecast changes in the number of fire weather days and season lengths, offering insights into when and where wildfires might occur when other conditions, such as fuel, are met, giving a much cleaner and more identifiable signal than other more stochastic fire measures such as burnt area (Jones et al., 2022). In regions such as Southeast Australia and parts of the western USA, where vegetation and fuel

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

loads are ample, fire weather indices are critical for predicting fire risk and are used to manage wildfire response. Conversely, in fuel-limited systems, such as arid grasslands or sparsely vegetated areas, fire risk is less dependent on weather and more on fuel accumulation, which complicates the use of FFDI in these contexts (Kelley and Harrison, 2014).

FFDI was developed in Australia by (Noble et al., 1980). The Australian Bureau of Meteorology uses it operationally to issue forecasts of fire weather for fire management and response (Dowdy et al., 2009; Dowdy, 2018). It is also applied in other regions like South Africa and Spain (De Groot et al., 2010; de Groot et al., 2015). Hoffmann et al. (2003) demonstrated a strong correlation between the FFDI and satellite estimates of actual fire occurrence in the Amazon. It has also been used successfully for global studies of the impact of climate variability and changes in future fire weather (Bett et al., 2020; Burton et al., 2018; Golding and Betts, 2008; Jolly et al., 2015).

As fire weather worsens, understanding how changes in global warming levels affect fire risk through operational indices like the FFDI can inform proactive management strategies. Unlike models targeting physical properties such as burnt area and fire intensity—which, despite rapid improvement, still face significant disagreement and uncertainty (Burton & Lampe et al. 2024a; Hantson et al., 2020; Kloster and Lasslop, 2017) —the FFDI offers a simpler way to represent crucial aspects of fire without introducing the non-linearities inherent in physical fire models. And by extrapolating short-term responses, fire indices can be used for longer-term forest management strategies, such as enhancing resilience through planning structure, resources, and preparedness, with a particular emphasis on preparedness as advocated by (UNEP et al., 2022). Preparedness sometimes includes adapting controlled burn practices, which are key in reducing fuel loads and mitigating wildfire severity later in a fire season (Burrows and McCaw, 2013; Morgan et al., 2020; da Veiga et al., 2024; da Veiga and Nikolakis, 2022). In Australia, for example, controlled burns are widely used to manage fuel loads, with operations typically concentrated during cooler months to minimize risks to human safety and biodiversity. However, an earlier onset of high-fire weather may shift these safe operating control burn windows, potentially leaving areas more vulnerable to intense fires later in the season. In the USA, particularly in the western regions, prescribed burns and mechanical thinning are standard practices for reducing fuel loads, especially in fire-prone areas near the wildland-urban interface (WUI) (Stephens et al., 2012). These measures are often conducted during periods of low wind activity to limit fire spread. Climate change, again, may complicate fuel management efforts as well as increasing risks during the peak fire seasons. In Brazil, controlled burns are less commonly employed in natural areas, with fire management primarily focusing on suppressing agricultural and pasture fires to prevent them from spreading into protected or ecologically sensitive regions, such as the Amazon rainforest or Pantanal wetlands. While there is significant attention to preventing deforestation and illegal burning in these regions, which can exacerbate fire risk, rising temperatures and prolonged dry periods are increasing the frequency and intensity of fires in these historically less fire-prone ecosystems. Integrated Fire management policies in parts of the Cerrardo, however, are starting to incorporate fuel management and control burns in early dry seasons to prevent more intense fires later in the year (Santos et al., 2021; Schmidt et al., 2018; da Veiga and Nikolakis, 2022). The FFDI's ability to integrate multiple

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

fire weather drivers and track seasonal changes in fire risk has the potential to provide critical insights for identifying safe operational windows under climate change. This capability already makes it a valuable tool for informing region-specific fire management practices and adapting them to changing fire weather conditions under today's climate.

The FFDI can also be calculated using components regularly output by climate models which, due to the uncertainty of how the earth's complex system will respond to increased greenhouse gas emissions, are used to explore different futures. While a single climate model provides insight into one possible future, using multiple climate models, or variations of a single model allows, for a broader exploration of potential futures. This approach increases the likelihood of capturing the actual future within the modelled scenarios, reducing unexpected "surprises" (Booth et al., 2013; Boulton et al., 2017) . A Perturbed Physics Ensemble (PPE) comprises numerous potential future outcomes based on variations of a single climate model, offering additional information compared to multi-model ensembles like the Coupled Model Intercomparison Projects (CMIP) (Booth et al., 2013; Lambert et al., 2013). Unlike CMIP, a PPE systematically samples a spectrum of possible futures, providing a way to address uncertainty. However, it is important to note that the original climate model's decisions and biases will be present in all sampled future scenarios.

We use a Perturbed Physics Ensemble (PPE) to explore how fire weather is projected to change under climate warming. Our analysis focuses on regions prone to extreme wildfires—Australia, the USA, and Brazil—and globally in non-fuel-limited ecosystems. We examine changes in the frequency and duration of Very High fire weather danger, as well as shifts in the timing of transitions from pre-fire to fire season, marking the shift from preparation to more direct firefighting and potential suppression efforts. Additionally, we investigate changes in the length of the High fire weather season length as a proxy for a safe yet effective controlled burn season, which is critical for fuel management, and assess the persistence of low-fire weather periods in regions employing seasonal firefighting strategies. These low fire weather periods represent essential windows for recovery and planning and may narrow as fire seasons extend with warming. By analyzing these dynamics across Global Warming Levels (GWLs) of 1.5°C, 2.0°C, and 4.0°C, we provide insights into how fire weather trends may challenge current management practices. This includes evaluating the mitigation potential of meeting Paris Agreement targets and identifying adaptive strategies to manage the increasing demands of a warming climate. Understanding these shifts is vital for developing proactive fire management approaches that enhance resilience, even under limited warming scenarios.

2 Methods

2.1 The Forest Fire Danger Index

We calculated the McArthur Forest Fire Danger Index (FFDI) using input variables from the HadCM3C Perturbed Physics Ensemble. The integration of FFDI with the HadCM framework ensures consistency with established

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

methodologies and benefits from extensive evaluation and a robust body of supporting literature, enhancing the reliability of our projections (Betts et al., 2015; Burton et al., 2018, 2020; Golding and Betts, 2008). The McArthur Forest Fire Danger Index (FFDI) is a widely used fire weather index that combines temperature, relative humidity, wind speed, and prior rainfall to assess the risk of fire occurrence and spread, particularly in fuel-abundant ecosystems. Originally developed for Australian forests, the FFDI is highly sensitive to temperature and relative humidity, making it well-suited for regions where climate-induced changes in these variables significantly influence fire risk (Dowdy et al., 2009). The FFDI also fulfils the balance of being simple enough to understand within our modelling framework whilst still being used operationally, especially in Australia, alongside other fire indices such as the Canadian fire weather index (Dowdy et al., 2009). As a result, the FFDI has also been used in global studies of fire weather under climate variability and change, often integrated with climate model output (Betts et al., 2015; Burton et al., 2018; Clarke and Evans, 2019; Golding and Betts, 2008; Jolly et al., 2015). One of the key strengths of the FFDI in this study is its high correlation with observed fire occurrences in tropical regions (Figure 1), as shown in studies such as (Hoffmann et al., 2003) for the Amazon, where seasonal dryness and extreme temperatures drive fire activity. The index's sensitivity to these meteorological factors is especially valuable in studies projecting future fire weather patterns, as it aligns closely with anticipated climate-induced shifts in temperature and humidity that will affect fire risk.

In comparison, the Canadian FWI, more commonly used in boreal and temperate ecosystems, has a reduced sensitivity to temperature and humidity shifts (Dowdy et al., 2010). This difference makes the FFDI particularly well-suited to regions such as Australia, the United States, and Brazil, where temperature and humidity play critical roles in fire dynamics (Forkel et al., 2017; Kelley et al., 2019). Although no single fire weather index is universally optimal (Yeo et al., 2015), the FFDI's responsiveness to key meteorological drivers provides essential insights into fire risk, especially under scenarios of climate change, which is central to understanding and managing future fire danger across a range of ecosystems.

The FFDI fire weather calculation is expressed as follows:

$$FFDI = 1.25 * DF \times \exp\left[\left(\frac{T-H}{30.0}\right) + 0.0234 \times V\right]$$

where DF = drought factor, T = daily maximum temperature at 1.5m (°C), H = daily relative humidity (%), and V = daily 10m wind speed (km/hr^{1}) (Noble et al., 1980).

The drought factor (DF) is calculated as:

$$DF = \frac{0.191 \times (SMD + 104) \times (N+1)^{1.5}}{(3.52 \times\times (N+1)^{1.5} + P - 1)}$$

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

where N = number of days since last rain, P = precipitation (mm/day) (Noble et al., 1980) and SMD = soil moisture deficit calculated using the models soil moisture to a soil depth of 1m compared to critical volumetric soil moisture corresponding to a soil matric water potential of -33 kPa (Best et al., 2011; Holgate et al., 2017). This provides a climate model representation of the Keetch-Byram drought index (KBDI) as in (Burton et al., 2018). This method of calculation can result in drier soils than the KBDI calculated from observed meteorology leading to fewer days in the Low-Moderate category of the resulting FFDI (Holgate et al., 2017). We, therefore, focus our results on patterns of changes in FFDI, or changes in time in each FFDI category as proxy of change, rather than FFDI itself. The drought factor is limited to 10, as suggested by (Sirakoff, 1985). The standard categories for the FFDI are given in Table 1. Throughout this study, we consider days above the "Very High" threshold, corresponding to days above a threshold of 24, as an indicator of fire season length. We also consider the "High" threshold, where the FFDI is greater than 12 and less than 24, as an indicator of the control burn season length (Levine et al., 2020). Changes in Low – Moderate give an indication of proportional changes in the fire off-season.

Table 1 FFDI categories (Chiara M. Holgate 2017)

Category	FFDI range
Low – moderate	$0 \leq \text{FFDI} < 12$
High	$12 \leq \text{FFDI} < 24$
Very High	$24 \leq \text{FFDI} < 50$
Severe	$50 \leq \text{FFDI} < 75$
Extreme	$75 \leq \text{FFDI} < 100$
Catastrophic	$100 \leq \text{FFDI}$

2.2 Models and data

We use a PPE of the Met Office Hadley Centre global climate model, HadCM3C. This ensemble includes 57 plausible variants of HadCM3C to sample uncertainties in atmospheric feedbacks, the land carbon cycle, ocean physics and aerosol sulphur cycle processes as described in (Booth et al., 2013) and used in (Taylor et al., 2013). This ensemble was designed to sample a large range of future global average temperatures. Importantly, unlike many other perturbed-parameter ensembles, the HadCM3C model includes dynamic vegetation coupled to the atmosphere model, allowing for biophysical vegetation-climate feedbacks, as well as climate-carbon cycle feedbacks. HadCM3C is part of a family of models based around the HadCM3 configuration (Gordon et al., 2000), which showed large reductions in precipitation in the Amazon region under future climate change projections associated with particular patterns of sea surface temperature (SST) change (Good et al., 2008; Harris et al., 2008). When dynamic vegetation is included, this leads to forest die-back in the Amazon (Cox et al., 2000), with

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

biophysical vegetation-climate feedback playing a key role in magnifying the circulation-induced precipitation reduction (Betts et al., 2004). The range of future global average temperature changes broadly spans the Coupled Model Intercomparison Project Phase 5 (CMIP5) projections, except at the lower end (Booth et al., 2013).

We use two future emissions scenarios related to the Representative Concentration Pathways (RCPs), a low-emissions scenario RCP2.6 and a high-emissions scenario RCP8.5, to explore a wide range of future climate outcomes. Since the HadCM3C model includes an interactive carbon cycle, the scenarios are used here as emissions scenarios instead of concentration pathways, as more commonly used in climate models that do not simulate the carbon cycle, such as the CMIP5 ensemble.

We look at changes in future fire weather at three GWLs, 1.5°C, 2.0°C and 4.0°C, defined relative to 1850–1900, as used in the IPCC 6th Assessment Report (Masson-Delmotte et al., 2021) and (Burton et al., 2021), for both emissions scenarios and each ensemble member. We calculated the relevant GWL for each ensemble member as twenty years surrounding the year that first passed the GWL threshold. This means that the time periods analysed for each GWL are not the same across the ensemble, as there is a range of future temperatures and periods when each model variant reaches them. We compare these changes in fire weather to a baseline period of 1986 – 2005, as used in the IPCC Special Report on Global Warming of 1.5°C. We also compare breakdowns of the length of the season in each FFDI category compared to the recent present (2004-2023).

2.3 Metrics calculated

We calculate five metrics;

- The daily 90th percentile of the FFDI
- The number of days over the Very High FFDI threshold
- The percent of the burnable land surface with an increase in fire weather (the land surface considered burnable after excluding non-burnable land as detailed below, rather than burned area).
- The shift in the date that experiences the same FFDI matching the end of the typical "fire management" season for each region: 31st Oct for Australia (Clarke et al., 2019); 1st September for Brazil (da Veiga et al., 2024; da Veiga and Nikolakis, 2022), 31st of May for USA (Houghton and Lewis, 1973; Knapp et al., 2009).
- The number of days in the High FFDI category (greater than 12, less than 24) as a proxy for potential control burn times – when conditions aren't so wet as to be ineffective but preceding fire season when efforts are often diverted to more active firefighting (Prescribed burning frequently asked questions, 2024; Levine et al., 2020).

We calculated the daily 90th percentile of the FFDI, globally and for each country of interest (Australia, Brazil and the USA) to explore the future response of the higher end of the FFDI to a warming world. This metric also allows us to explore the response of the seasonal cycle of the higher end of the FFDI. We then calculated the number of days in the, Low-Medium, High and above the Very High FFDI and above thresholds.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

We calculate each metric across the globe, focusing on Brazil, Australia and the USA. These regions were chosen because of recent significant and multiple fire seasons in all three with considerable impacts, the emerging signal of climate change in these regions, and the exploration of a range of regions across the world. Each metric was calculated for the 2 emissions scenarios (RCP2.6 and RCP8.5), and the three global warming levels – baseline, 1.5℃, 2.0℃, and 4.0℃. For the mitigation scenario, RCP2.6, all 57 members of the ensemble reach 1.5℃, 50 members reach 2.0°C, and no ensemble members exceed 4.0°C. Whereas the high-end scenario, RCP8.5, shows all ensemble members reaching 4.0°C.

We identified non-burnable land by applying the SAGE potential vegetation database to the baseline period (1985 – 2005) for areas with either ice or where greater than 50% of the model grid square was bare soil as used in Bett et al. (2020). This non-burnable land was masked out in the calculation of these metrics.

3 Results

3.1 Evaluation of the modelled FFDI vs reanalysis

We start with evaluating FFDI from model simulations against FFDI constructed from observations. Figure 1 shows the number of days above the Very High FFDI threshold ("fire weather days") for the PPE model baseline period, 1986– 2005 (1a), compared to the same FFDI metric and time period calculated from Copernicus reanalysis data. The modelled fire weather broadly matches that from the reanalysis. Modelled FFDI in Figure 1 is presented as consensus plots of the 57-member ensemble and is being compared to one realisation of the reanalysis results from Copernicus, so we would not expect them to align directly because the PPE was designed to sample a wide range of climate variability. However, simulated fire weather does occur in regions of observed FFDI except over northern American boreal regions (Figure 1). These boreal regions are not typically represented as having High fire risk due to their low average temperature, especially in fire indices designed for sub-tropic regions such as the FFDI. There is also a high occurrence of peat fires in this area which are difficult to represent in both fire indices and fire-land surface models, as these long-lasting smoldering fires behave very differently from forest and grass fires (Blackford et al., 2024). We, therefore, do not include a high-latitude region in our regional analysis.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

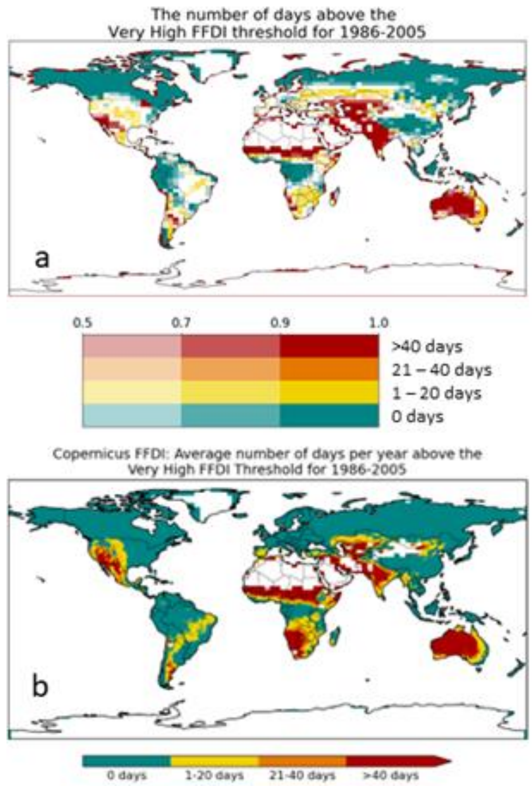


Figure 1 Comparison of the average number of days per year above the Very High FFDI threshold in 1986-2005 for (a) HadCM3C PPE historical and (b) with the Copernicus FFDI for the same metric and time period (CMES, 2019)**. The model ensemble data shows the model agreement (consensus) across the PPE shown by the colour bar in the lower left corner (for panel a but not panel b). The numbers on the colour bar refer to the percent of models that agree with the band of number of days. White regions indicate low model agreement and the non-burnable land surface**

3.2 Increases in Very High fire weather.

We use Very High fire weather (>24, Table 1) to determine changes in the fire season length. Table 2 gives the percent of the burnable land with an increase in the number of days above the Very High FFDI threshold globally, as well as for Australia, Brazil, and the USA, for the three GWLs and both emissions scenarios. Globally, we project between 30% (central estimate, 25-34% across the ensemble) at 1.5°C to 50% (41-58%) at 4.0°C of burnable land with increased fire weather days under higher emissions (RCP8.5). Limiting warming to 2.0°C with the mitigation scenario (RCP2.6) gives 35% (31-42%) and 31% (25-36%) if we limit to 1.5°C .

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Table 2 The percent of the burnable land with an increase in the number of days above the Very High FFDI threshold (compared to 1986 – 2005) showing the 50th percentile (central estimate) of the PPE ensemble and the 10th and 90th percentiles in brackets below, for the three GWLs (1.5°C, 2.0°C and 4.0°C).

Region	Scenario	Global Warming Level		
		1.5°C	**2.0°C**	**4.0°C**
Global	**RCP2.6**	31% (25 – 36)	35% (31 – 42)	
	RCP8.5	30% (25 – 37)	36% (31 – 44)	50% (41 – 58)
Australia	**RCP2.6**	82% (46 – 94)	87% (46 – 97)	
	RCP8.5	73% (37 – 95)	87% (55 – 97)	95% (88 – 100)
Brazil	**RCP2.6**	30% (12 – 48)	45% (26 – 57)	
	RCP8.5	30% (17 – 48)	41% (24 – 58)	70% (52 – 83)
USA.	**RCP2.6**	33% (14 – 51)	42% (20 – 60)	
	RCP8.5	34% (17 – 57)	44% (18 – 65)	65% (40 – 79)

Australia has the largest amount of its burnable land surface with an increase in fire weather at all future GWLs, ranging from 73% (37-95%) at 1.5°C to 96% (88-100%) at 4.0°C under higher emissions. For the mitigation scenario, 87% (46-97%) at 2.0°C and 82% (46-94%) at 1.5°C of the land show an increase in fire weather days. Most of Australia is fuel-limited (Kelley et al., 2019), and vegetation productivity changes will likely have a strong influence on the resultant burnt area and fire intensity in the future (Haas et al., 2024). However, we show the same pattern in the more populated and moisture-limited southern Eastern Australia (Figure 2), though with slightly less agreement in this region at 1.5°C. Across Brazil, 30% (17-48% at 1.5°C) to 70% (52-82% at 4.0°C) of the burnable land has an increase in fire weather days. There is a considerable increase between 1.5°C and 2.0° for both emissions scenarios, with 45% (26% to 57%) of the burnable land experiencing an increase in fire weather days at 2.0°C for RCP2.6. For the USA, our simulations indicate between 34% (17-57% at 1.5°C) and 65% (40-79% at 4.0°C) of the burnable land experiencing an increase in fire weather days in RCP8.5 with the mitigation scenario limiting it to 44% (18-65%) at 2.0°C for RCP2.6.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

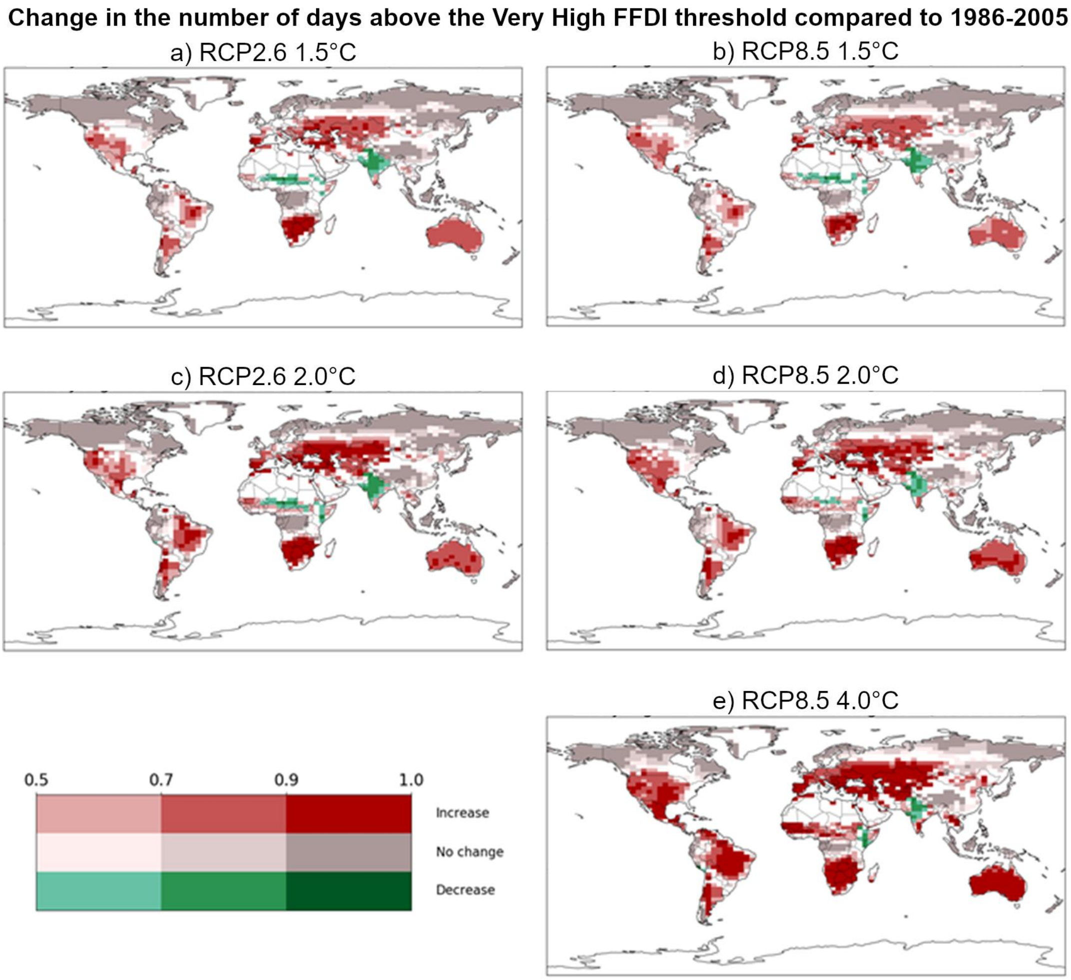


Figure 2 The change in the number of days above the Very High FFDI threshold presented as consensus plots showing model agreement across the 57-member PPE using the method of Kaye et al. (2012) as implemented in Taylor et al. (2013) to show areas of ensemble member agreement, or "consensus". Red indicates areas with an increase in the number of days, compared to the baseline period (1986 – 2005). Grey is no change and green indicates a decrease. The darker the colour, the more models agree with that change. White areas indicate no clear consensus. Non-burnable land has been excluded and appears white. For RCP2.6 (panels a and c) and RCP8.5 (panels b, d, f) and three GWLs, 1.5°C (panels a and b), 2.0°C (c,d) and 4.0°C (panel e)

We also calculate the number of days above the Very High FFDI threshold, averaged across the twenty-year GWL period, to give an annual average of threshold exceedance for each GWL (Figure 2, Table 3). Globally, the average number of days exceeding the Very High FFDI threshold increases even at 1.5°C of warming (0.95 central estimates, or 0.59-1.26 for 10-90th percentile for RCP2.6, and 0.88, 0.56-1.4 for RCP8.5), with more substantial

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

increases at higher GWLs (Table 3). While the changes are small in terms of global averages, the patterns are consistent across regions, with only slight differences between RCP2.6 and RCP8.5 at 1.5°C and 2.0°C. However, RCP2.6 does avoid the substantial regional increase in Very High fire weather days, which are projected at 4.0°C in RCP8.5. Regionally, Australia experiences the largest and most consistent increases in fire weather days, with all percentiles and emissions scenarios indicating positive changes, particularly at 2.0°C (9.82, 1.08-17.08 for RCP2.6 and 10.64, 3.14-18.45 for RCP8.5) and 4.0°C (21.07, 13.19-34.89 for RCP8.5). Brazil also shows notable though less pronounced increases by 4.0°C (10.83, 4.59-19.71, RCP8.5) and with much smaller increases under mitigation (i.e. 0.98, 0.27-3.05 at 1.5°C in RCP2.6). The USA increases shows more uncertainty across the perturbed physics ensemble (PPE). By 4.0°C (9.26, 3.97-15.40 for RCP8.5), though much less of an increase, with even uncertainty that there will be increase, at lower warming levels (2.19, -0.03-4.91 for RCP2.6 and 2.07, -0.23-4.83 for RCP8.5 at 1.5°C). By 4.0°C, all regions exhibit clear and considerable increases in fire weather days, emphasizing the growing fire risk with warming.

Table 3 The average (over land and excluding non-burnable land) change in the number of days above the Very High FFDI threshold (compared to 1986 – 2005) for the two scenarios, RCP2.6 and RCP8.5, the three Global Warming Levels, 1.5°C, 2.0°C and 4.0°C, showing the 50th percentile (central estimate) of the PPE ensemble and the 10th and 90th percentiles in brackets below.

Region	Scenario	Global Warming Level		
		1.5°C	**2.0°C**	**4.0°C**
Global	**RCP2.6**	0.95 (0.59 – 1.26)	1.49 (1.0 – 2.08)	
	RCP8.5	0.88 (0.56 – 1.4)	1.5 (1.13 – 2.37)	4.87 (3.32 – 8.04)
Australia	**RCP2.6**	6.38 (0.24 – 14.61)	9.82 (1.08 – 17.08)	
	RCP8.5	6.82 (-1.56 – 13.71)	10.64 (3.14 – 18.45)	21.07 (13.19 – 34.89)
Brazil	**RCP2.6**	0.98 (0.27 – 3.05)	2.52 (1.01 – 4.71)	
	RCP8.5	0.99 (0.3 – 2.62)	1.95 (0.76 – 4.47)	10.83 (4.59– 19.71)
USA.	**RCP2.6**	2.19 (-0.03 – 4.91)	2.77 (0.21 – 6.42)	
	RCP8.5	2.07 (-0.23 – 4.83)	3.35 (0.26 – 6.54)	9.26 (3.97 – 15.40)

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

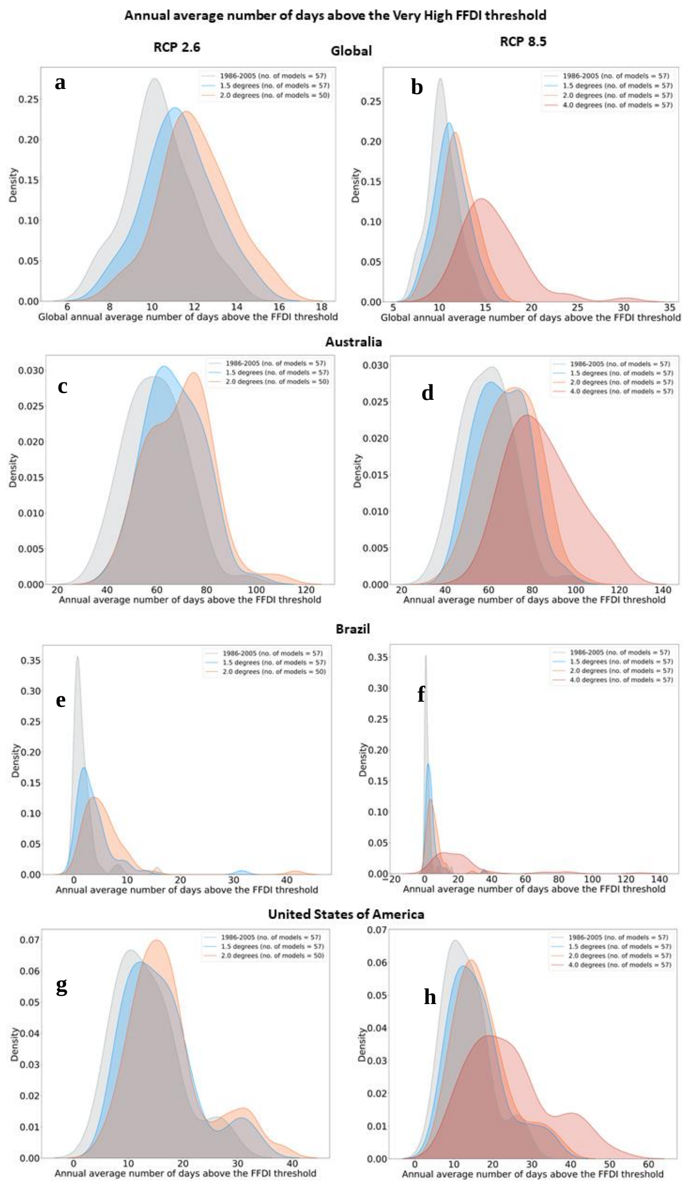


Figure 3 The annual average number of days above the Very High FFDI threshold for 3 future Global Warming Levels, 1.5°C, 2.0°C and 4.0°C and the baseline of 1986 – 2005, for 2 emissions scenarios, RCP 2.6 (a mitigation scenario, panels a,c,e,g) and RCP 8.5 (a high-end scenario, panels b,d,f,h), globally (panels a and b), and for Australia (c, d), Brazil (e, f) and the USA (g, h).

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

There is a clear shift in the distribution of the number of days per year with Very High FFDI, indicating a lengthening fire season as temperatures rise (Figure 3). Globally and for Australia, the minimum number of days meeting the Very High threshold increases substantially. For example, in Australia, the minimum number of days with Very High FFDI is 20 during the baseline period (1986–2005), rising to 37 at 1.5°C and 2°C under both RCP2.6 and RCP8.5, and reaching 40 at 4°C under RCP8.5. For Brazil and the USA, the distribution retains some years with no Very High FFDI days even at 4°C, reflecting ongoing variability in fire weather extremes. However, the median and upper-end estimates shift significantly toward longer fire seasons. The most concerning changes occur in the extreme tails of the distribution, particularly for Brazil and the USA. In Brazil, there is a small likelihood during the baseline period of a peak around 15 days per year meeting the Very High FFDI threshold. This increases sharply to 32 days at 1.5°C, 42 days at 2°C, and as many as 90–140 days at 4°C. For the USA, the increase in the extreme tail is smaller in magnitude but still substantial, with the likelihood of very long fire seasons increasing, from around 30 days at the baseline to up to 60 days at 4°C.

3.3 Mitigation potential

Figure 4 illustrates the mitigation anomaly, representing the difference in Very High fire weather days between a GWL of 4.0°C and the lower warming levels of 2.0°C and 1.5°C. Globally, all ensemble members indicate fewer Very High fire weather days when warming is limited, with the entire PPE ensemble showing values above zero. This consistent reduction highlights the clear benefits of mitigation in reducing fire weather days. Similar trends are observed across the three regions, where most ensemble members project reductions, though a few members show a low likelihood of slight increases. Notably, the difference between 1.5°C and 2.0°C is relatively small, underscoring the value of staying well below 4.0°C to minimize fire risk.

There is strong consensus for increases in fire weather days across the eastern USA, Brazil, southern South America, southern Africa, northern Africa, southern Europe, central Asia and Australia (Figure 2). Both 1.5°C and 2.0°C look broadly similar for both emissions scenarios; however, there are spatial differences in the extent of increases and the amount of consensus. The number of fire weather days and the level of consensus increases with warming levels across all regions wherever there is a rise in fire weather. There are also consistent areas showing decreases across the tropics in India and Africa, which continue to 4.0°C, though over a reduced spatial area. Western USA and Eastern Amazon show a reasonable consensus (normally > 70%) for an increase in Very High FFDI at 1.5°C. However, areas affected by the Black Summer fires along Southeast Australia show less consensus, often < 50%, at 1.5°C. Consensus increases in all these regions at 2°C and approaches 100% by 4°C.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

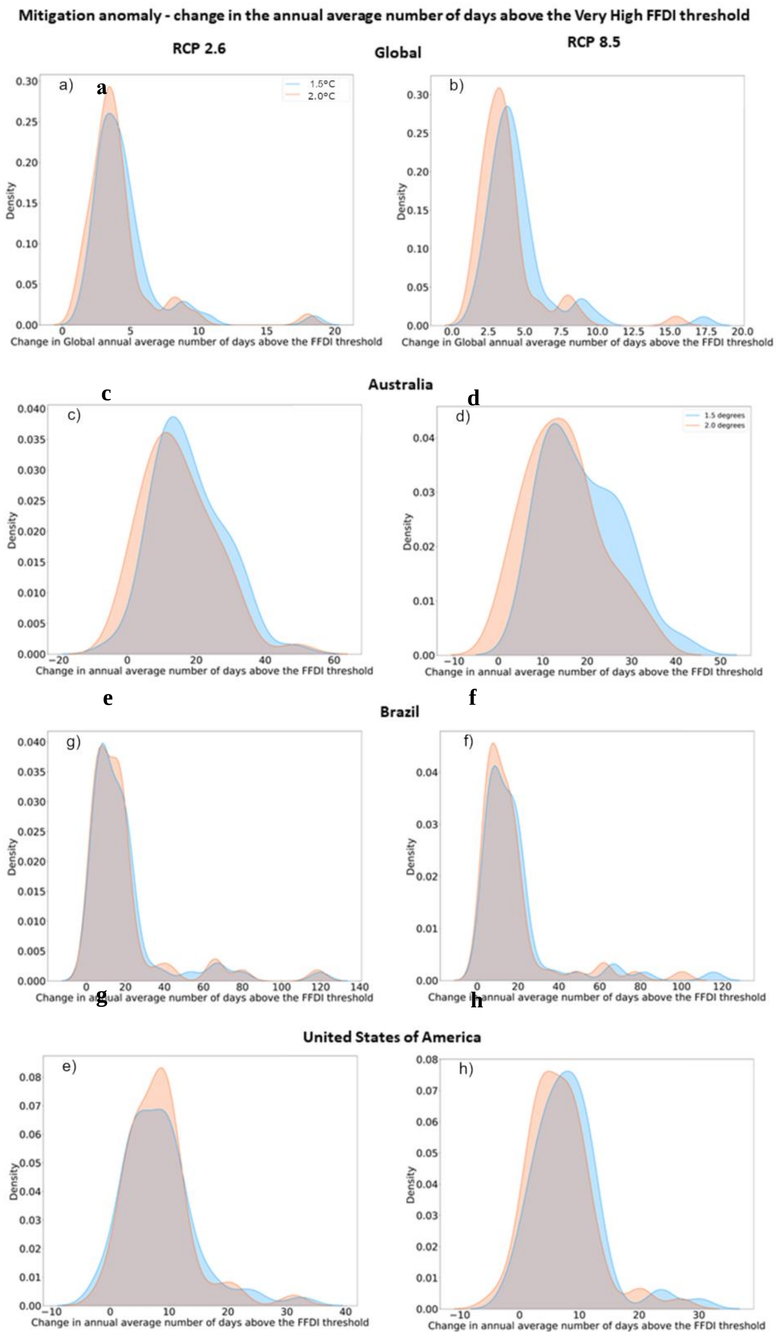
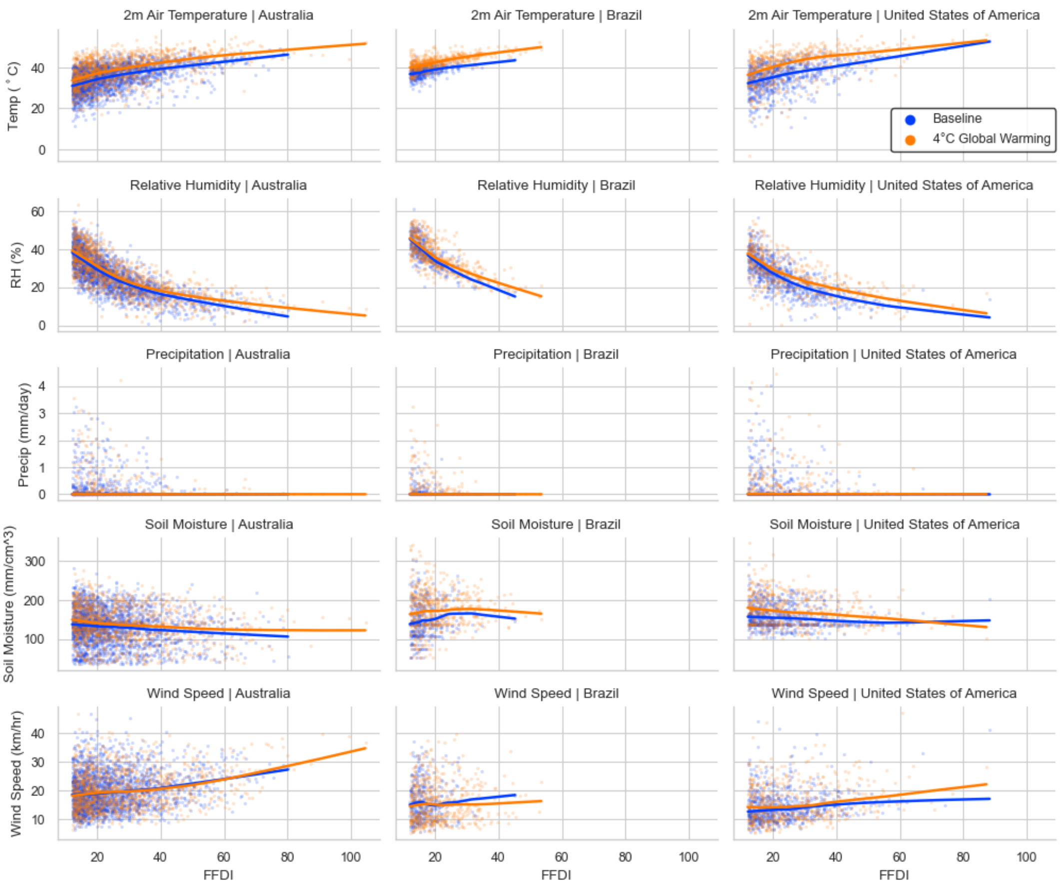


Figure 4 The mitigation anomaly of the change in annual average number of days above the FFDI threshold, calculated as the difference between 4.0°C GWL (RCP8.5) and 1.5°C (blue) and 2.0°C (orange) respectively, for both emission scenarios. RCP2.6 (left column, panels a, c, e, g) and RCP8.5 (right column, panels b, d, f, h), Globally (panels a and b) and for Australia (c,d), Brazil (e,f) and the USA (g,h)

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

3.4 Meteorological drivers of FFDI

Next, we examine the meteorological factors influencing changes in fire weather days to help understand the aspects of climate that change future fire risk. We sampled grid cells with High (12) FFDI or greater within the 20-year baseline period and within the 20-year 4°C global warming period for each model, Australia, the USA, and Brazil (Figure 5). Brazil generally has lower FFDI extremes than Australia in the 4°C world. USA high FFDIs are more sensitive to small changes in relative humidity (RH) rather than temperature, which is also found in other independent studies (Volpato et al., 2023). Also, the steeper curve for RH in Brazil shows that RH has more influence on lower FFDI values than in the other countries, though temperature becomes important at higher FFDIs, especially at 4°C. Whereas in Australia and the USA, relatively small reductions in RH values below 20% have a larger influence on FFDI values above 40. At 4°C global warming, Brazil is also projected to see the biggest changes in FFDI, with more days at more extreme FFDI values due to higher temperatures and lower RH.



https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Figure 5 A sample of grid cells and ensemble members showing the FFDI (x-axis) vs each variable (rows) used for its calculation (temperature, relative humidity, precipitation, soil moisture and wind speed), for the three countries (Australia, Brazil and the USA). The blue dots and line are for the baseline time-period and the orange dots and line are for the 4°C GWL. Trendlines have been applied using Loess fit.

3.3 Change in FFDI seasonal cycle

In this section, we focus on the implications of changes in FFDI values over the full fire season, to inform seasonal fire management practices across different regions. For this, we calculated the daily 90th percentile for each model grid cell, averaged across every 20-year period at each GWL (Figure 6). All three countries show a distinct seasonal cycle of increased fire weather in the spring/summer and lower FFDI in the winter for the baseline – a cycle still maintained for all levels of warming. Brazil and the USA both have very low FFDI values in the winter, whilst Australia has a higher wetter season FFDI. For 1986 – 2005, the PPE ensemble shows considerable spread across all three countries during periods of higher fire weather. There are increases in fire weather throughout most of the fire season, even at 1.5°C, with larger increases at higher warming levels. At higher warming levels, the peak FFDI values also increase, and the range of values across the ensemble increases even whilst the minimums stay largely the same.

Table 4: **Projected shift in the end-of-season date for controlled burns in Australia, Brazil, and the United States at each global warming level (GWL). Calculated as the number of days earlier in the year that the FFDI reaches the baseline threshold typically marking the end of the burn season: 31st October for Australia, 1st September for Brazil, and 31st May for the USA. Values show the 10th and 90th percentiles across ensemble members, indicating the range of projected changes.**

			Australia	Brazil	USA
	GWL		End of October	Early September	Late May
RCP2.6	1.5°C	10th	5	9	17
		90th	12	13	18
	2°C	10th	22	16	11
		90th	22	16	19
RCP8.5	1.5°C	10th	5	11	24
		90th	21	26	24
	2°C	10th	9	22	8
		90th	17	22	24
	4°C	10th	25	34	28
		90th	33	50	40

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

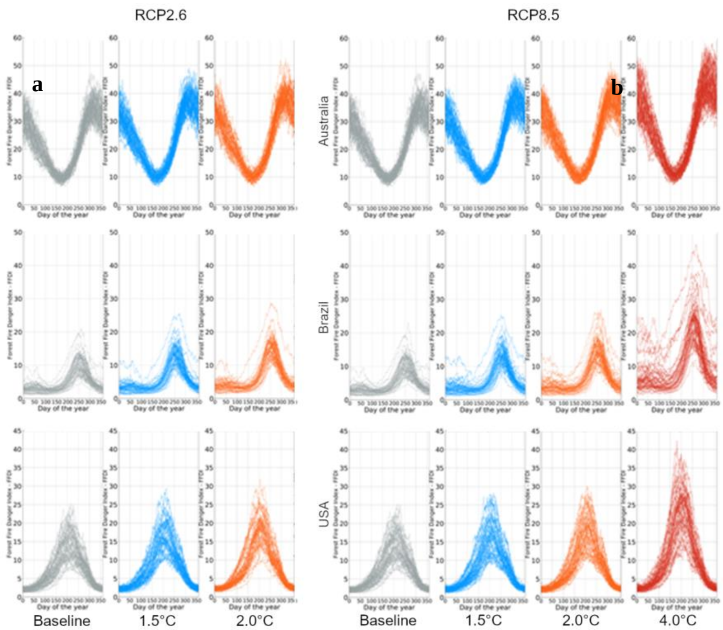


Figure 6 Daily 90th percentile of future fire weather as represented by the FFDI for the baseline (1986-2005), and 3 future Global Warming Levels, 1.5°C, 2.0°C and 4.0°C for two emissions scenarios, RCP2.6 in panels a, c, e and RCP8.5 in panels b, d, f, for Australia (panels a and b), Brazil (panels c and d) and the USA (panels e and f)

As is expected, each country has a different range of FFDI values for the baseline and future GWLs, reflecting the respective climates of those regions. Australia exhibits significant changes in its burn season timing, with the end-of-season threshold occurring approximately 5–22 days earlier under RCP2.6 at 1.5°C and roughly 22 days earlier at 2°C, depending on ensemble member spread (**Table 4**). Under RCP8.5, end-of-season shifts could be up to 24 days earlier. In Brazil, the seasonal shift is less pronounced but still notable, with the end-of-burn season threshold advancing by approximately 9–13 days under RCP2.6 at 1.5°C and reaching up to 16 days at 2°C. Under high-end warming (RCP8.5), the threshold moves up to 11 days earlier. In the USA, end-of-burn season thresholds advance by approximately 17–24 days under RCP2.6 at 1.5°C and up to 24 days earlier under RCP8.5 at 1.5°C. While the USA's fire season shifts less dramatically than Australia's, this change marks a significant adjustment, likely affecting spring/summer management. The consistency of these patterns across regions reinforces the importance of adapting the timing of pre-season fire management practices to changing conditions. Across all three regions, even at the highest warming levels, distinct periods of low fire weather in winter remain. These retained low-fire periods provide strategic windows for fire season preparation, fuel reduction and control burning, resource planning and as an off season for seasonal firefighting. However, the consistent advancement of season-end dates underscores an increasingly compressed non-fire season.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

3.5 Change in Low to High FFDI

We also evaluate projected increases in High fire danger days across Australia, Brazil, and the United States under historical, current, and future GWLs (Figure 7), which is a proxy for changes in the amount of time control burns that might be conducted – i.e, not so wet for fire control burns to be ineffective, but without so higher fire weather as to risk fire's becoming out of control. Exact FFDIs for control burns vary among and even within a region, depending on the risk to local populations, fuel loads, and need depending on the likelihood of later extreme fires (Cirulis et al., 2020; Gill et al., 1987; Howard et al., 2020; da Veiga and Nikolakis, 2022). So 'High' serves as a proxy and indication of weather-related changes only.

Across all three regions, increases in High, as well as Very High, fire danger days are projected, especially under scenarios exceeding 1.5°C, though 1.5°C still shows substantial increases. Australia exhibits the highest baseline levels of fire danger among the regions analysed, with 132.61 days per year at or above High fire danger between 1986 and 2005. In the present day (2004–2023), our model indicates that this may have increased by an additional 7 days annually. At 1.5°C warming, High fire danger days will increase by approximately 9.53 days under the RCP2.6 scenario and 8.37 days under RCP8.5, with even more significant increases at 2°C and higher GWLs. Brazil historically had much lower annual High fire danger days than Australia, with an average of 16.99 days per year from 1986 to 2005. Since then, there has been an increase of 5 days, bringing the present-day average to approximately 21.99 days annually. At 1.5°C, Brazil's High fire danger days are projected to increase by 7.12 days under RCP2.6 and 6.92 days under RCP8.5, indicating a notable shift towards higher fire potential even at this lower warming level. The United States had an average of 29.31 High fire danger days annually from 1986 to 2005, with an increase of 3.51 days observed by the present day, making current annual totals approximately 32.82 days. Projections at 1.5°C warming indicate additional increases of around 3.82 days under RCP2.6 and 3.76 days under RCP8.5. Though the USA's increases are smaller than Australia's, the cumulative effects of additional High AND Very High fire danger days will still likely strain current, often seasonal fire management resources and underscore the need for adaptive strategies, especially in high-risk regions like the western United States.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

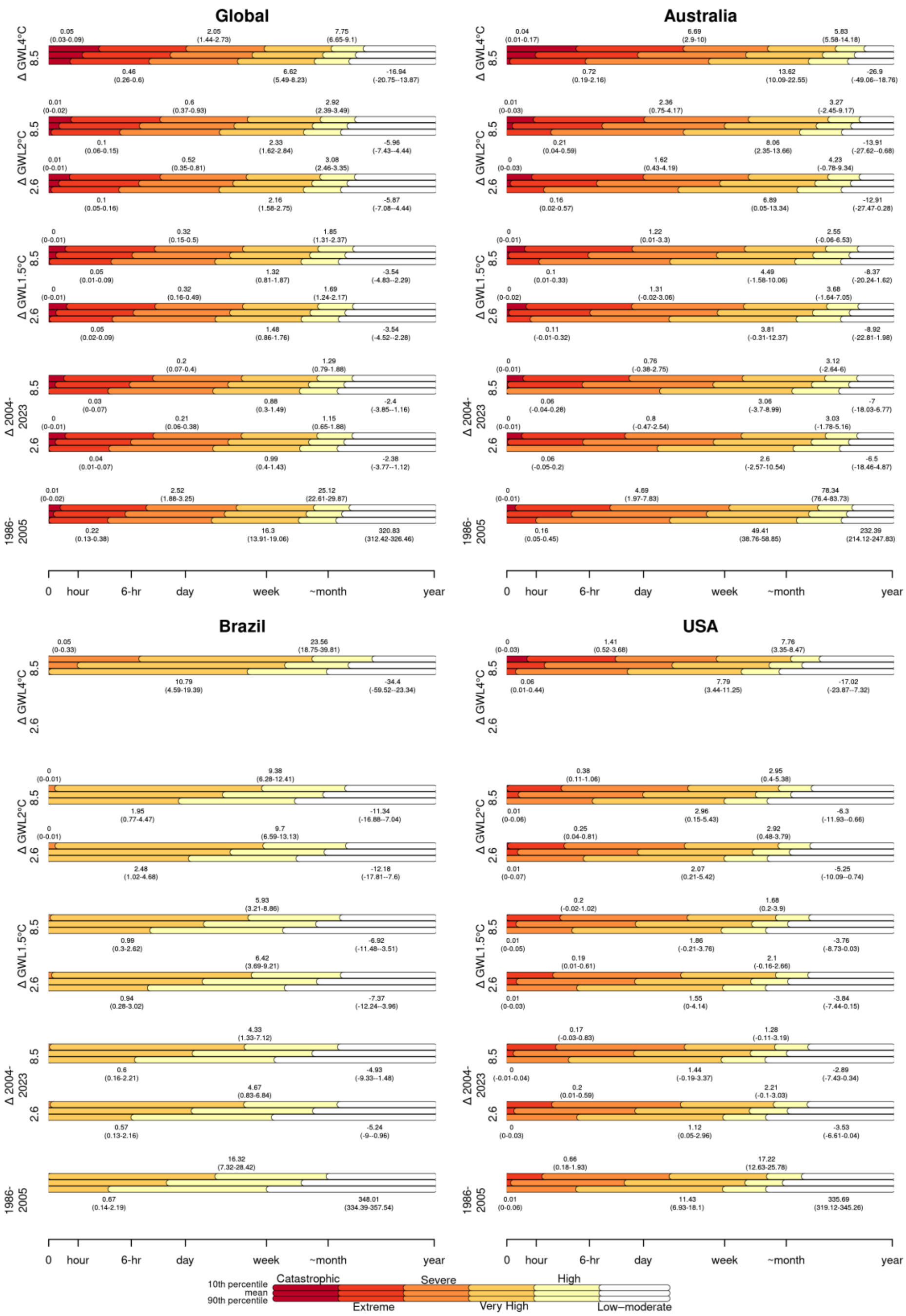


Figure 7: Projected changes in annual time spent in different fire weather categories across Australia, Brazil, and the United States under various Representative Concentration Pathways (RCPs) and Global Warming

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Levels (GWLs). The bottom row for each region shows historical averages (1986–2005) of annual time spent in each Fire Danger Index category, from Low-Medium (white) to High through Catastrophic (yellow to deep red), as defined in Table 1. Rows above (from bottom to top) display changes under present-day conditions (2004–2023) and future projections at 1.5°C, 2°C, and 4°C global warming levels.

Globally, the Low–moderate FFDI category decreases by approximately 2.4 days at 1.5°C and by nearly 17 days at 4°C under RCP8.5. These reductions suggest significant global shifts in the duration of periods typically associated with low fire risk. Across all regions, there is a clear trend towards a reduction in the time spent in the Low–moderate FFDI category, accompanied by an increase in the time spent in the higher FFDI categories. This reflects a contraction of the low fire-risk period and a corresponding extension of fire-prone conditions. Australia exhibits the most pronounced changes, with a decrease in the Low–moderate category of approximately 7 days at 1.5°C, extending to over 26 days by 4°C under RCP8.5. In the USA, the decrease in the Low–moderate category is less pronounced, with reductions of approximately 1 week at 1.5°C and up to 10 days at 4°C under RCP8.5. Brazil also demonstrates a marked decline in time spent in the Low–moderate category - up to 12 days at 2°C and over 26 days at 4°C.

The increases in the more extreme FFDI categories (Severe, Extreme, Catastrophic) provide a useful proxy for understanding changes in fire behaviour under climate change. Globally, time spent in the Extreme category shows a modest increase of ~0.1 days at 1.5°C, reaching ~0.5 days at 4°C under RCP8.5. The most dramatic changes occur in the Severe category, which increases by ~0.6 days at 1.5°C and ~2 days at 4°C. Time spent in the Extreme category in Australia increases significantly, particularly under higher warming levels, reaching an additional ~0.7 days by 4°C under RCP8.5. Similarly, the Severe category grows by over 6 days by 4°C, suggesting heightened risk of extreme fire weather events. Although changes are smaller in USA, there are notable increases in the Severe category, reaching 2–3 days at higher warming levels. Brazil shows smaller increases in extreme categories, with the Very High category dominating changes.

4. Discussion

Our model projections show that the more global warming we experience in the future, the higher the fire risk, and the longer Very High fire weather seasons will become, extending over much more land area, especially at 4°C global warming. We show significant sensitivity of fire weather to global warming levels, with increases in Very High fire weather days (FFDI > 24) projected globally and regionally at all temperature thresholds. At 4.0°C, we project an increase in Very High fire weather days over 50% of affected burnable land worldwide, compared to 30% at 1.5°C global warming. This highlights the disproportionate impact of higher warming levels and the urgent need for mitigation to limit global temperatures.

Regionally, Australia emerges as particularly vulnerable, with 82% of its burnable land impacted at 1.5°C, rising to 87% at 2.0°C and 96% at 4.0°C (RCP8.5 central estimate, Table 2), with increases seen even in the fuel-abundant

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

southeast coast. While the increases between 1.5°C/2.0°C and 4°C highlight the benefits of limiting warming, the high proportion of affected land, even at lower thresholds, emphasises that adaptation will also be necessary. In Brazil, fire weather also shows a marked escalation, with 30% of burnable land affected at 1.5°C, increasing steeply to 45% at 2.0°C. This jump reflects the acute sensitivity of Brazil's ecosystems, already under pressure from deforestation and land-use change (Ferreira et al., 2023; Kelley et al., 2021; Mataveli et al., 2022).. In the USA, fire weather increases more steadily, but still markedly, with 33% of burnable land affected at 1.5°C and 42% at 2.0°C. Together, these illustrate that there will likely be regional variation in how fire risk may respond differently to warming in diverse landscapes. However, all regions still show an increase even at 1.5°C.

RCP2.6 (the mitigation scenario) limits global warming to much lower temperatures than RCP8.5. However, at the lower warming thresholds, fire weather changes are primarily driven by GWLs, with relatively little variation between emissions scenarios– evidence of the critical role of achieving and maintaining Paris Agreement targets. Mitigation to limit warming to well below 2.0°C presents a substantial opportunity to reduce the area affected by worsening fire weather, but even at 1.5°C, our results suggest that increases in Very High fire danger days are unavoidable. Any policy response to this projected increase in future fire weather ideally needs to address these two elements that should complement and support each other. Firstly, an effective global mitigation policy is needed to limit future climate change and hence limit the increase in future fire weather days. Secondly, enhanced fire management policies are needed to respond to the unavoidable increases in fire weather days that are projected for all global warming levels.

The extent of FFDI increases varies across our study regions, along with shifts in the timing and duration of fire seasons and differences in regional sensitivities to key climate drivers. These findings suggest that each region's fire season responds differently to climate change and therefore need tailored adaptation strategies (Barbosa et al., 2022; Pandey et al., 2023). Brazil, for example, generally experiences lower FFDI values compared to Australia and the USA, and our results suggest that relative humidity plays a more critical role than temperature in shaping fire danger, particularly at lower FFDI levels (Figure 5) associated with many of Brazil's forests and wetland areas. This suggests that maintaining higher humidity levels, such as above 20%, could play an important role in mitigating fire risk in Brazil's humid, fire-sensitive biomes(Ferreira Barbosa et al., 2024). Approaches that have been proposed or implemented, such as conserving forests, protecting wetlands, especially in the Pantanal(Ferreira Barbosa et al., 2022), and preventing fragmentation of riparian zones (Ferreira Barbosa et al., 2024; Ferreira et al., 2023), may help sustain soil moisture, maintain humidity levels, and act as natural firebreaks. These strategies could also integrate water conservation with fire risk mitigation. In regions with significant human influence, such as the Amazon and Pantanal (Ferreira Barbosa et al., 2022; Kelley et al., 2021), addressing both climatic and human factors is essential for understanding and mitigating fire weather-related risks. Large, destructive fires play a critical role in shaping fire regimes in these areas, often accounting for a substantial portion of the burned area during fire seasons (Flannigan et al., 2016). Our findings indicate that increased fire weather days in these regions elevate the potential for ignition and precondition the environment for large, impactful events. In the Cerrado, where FFDI is generally higher and fire danger more temperature-driven, forecasting periods of elevated fire danger (Anderson et al., 2022; Barbosa et al., 2022), and reducing human-sourced ignitions, such as restricting agricultural burning during peak fire weather, have been identified as strategies to reduce fire occurrence, particularly in agricultural and transitional zones(Ferreira Barbosa et al., 2021, 2022). Evidence suggests that controlled burns are effective in reducing late dry-season fires in areas surrounding the Cerrado (Santos et al., 2021; da Veiga et al., 2024; da Veiga and Nikolakis, 2022) Our findings indicate that the window for applying controlled burns may expand in the future, potentially by 9–13 days at 1.5°C under RCP2.6 and up to 16 days at 2°C (Figure 7). However, this expansion in high FFDI time—up to a week at 1.5°C and as much as a month at 4°C (Figure 7)—will likely coincide with a contraction of time in the Low–Moderate category, potentially increasing the window in which seasonal firefighting is required.

In Australia, fire danger is strongly influenced by low relative humidity, high temperatures, and high winds, which exacerbate fire spread and intensity. Our findings imply that fire management efforts in these areas might be most effective if they focus on reducing fuel loads, which today is often achieved through controlled burns during milder weather conditions (Morgan et al., 2020; Russell-Smith et al., 2020), and strengthening effective early warning systems that monitor RH, temperature, and wind speeds (de Groot et al., 2015). The end of the controlled burn season in Australia shifts significantly earlier, occurring approximately 5–12 days earlier under RCP2.6 at 1.5°C and up to 22 days earlier under 2.0°C (Table 4), though notably with a slightly longer period of High FFDI of almost a week by 4°C, during which time controlled burns may occur. These largely agree with the earlier and longer control burn season by mid-century found by (Clarke et al., 2019). However, like Brazil, the Low-Moderate off-season will also reduce, possibly by almost a month, at 4°C, which could substantially impact the way many of the heavily seasonal volunteer rural fire services recruit (Russell-Smith et al., 2020). Shifts in the timing of policies to reduce human ignition, such as closing national parks and restricting campfires during high-risk periods, could complement these measures by preventing fires from starting in the first place. However, our results indicate that some of these firefighting and restrictive measures would very likely be required for longer, even by 2°C, which could have associated firefighter and general compliance fatigue (Doley et al., 2016). Additionally, integrating fire-resistant vegetation and buffer zones around vulnerable areas could help mitigate risks associated with wind-driven fires (Pandey et al., 2023).

In the USA, High fire weather is primarily linked to temperature and wind, particularly in the western regions where strong, dry winds are common. The results suggest that targeted controlled burns during periods of lower wind activity, alongside mechanical thinning to reduce fuel loads, could be important strategies. The USA also sees advancement in the end-of-controlled burn season by approximately 17–24 days under RCP2.6 at 1.5°C and up to 24 days earlier under RCP8.5 (Table 4). These changes, while less dramatic than in Australia, mark a significant adjustment likely to impact spring/summer management practices. Increased length of the fire season and decreased length of the Low-Moderate season may also, like Australia, need to be factored into firefighting recruitment and wellbeing (O'Brien and Campbell, 2021). Efforts to reduce human ignitions, particularly in the wildland-urban interface, could further alleviate fire risks, given that many large fires originate from human activities.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Across all three regions, even at the highest warming levels, distinct periods of low-fire weather in winter remain. These retained low-fire periods provide strategic windows for resource planning, but the consistent advancement of season-start dates demonstrates an increasing need for earlier shifts for pre-season preparation within fire season firefighting and management as global temperatures rise. Projections indicate consistent increases in both High and Very High fire danger days with each level of warming, with the most substantial shifts seen in Australia and Brazil. The slight but significant projected increases in the Severe and Extreme categories, particularly in Australia, reflect a growing likelihood of extreme fire events requiring enhanced firefighting and emergency response capacities. By focusing on region-specific dynamics, preparing for extended fire seasons, and adapting controlled burn strategies to account for earlier season dates and potentially longer periods of control burn season length, fire management practices may be optimised to minimise the impacts of intensifying fire risks.

Globally, longer-term strategies, such as sustainable forest and land management practices that prevent deforestation or conserve wetland areas should align with mitigation goals and contribute to building resilience to rising fire weather risks. Building wildfire-adapted communities, particularly in regions where fire intersects with human infrastructure, can reduce fires' social and economic impacts when they do occur. Fire management focused on strategic planning and prevention will be critical in managing fire risks across diverse fire-prone regions (UNEP et al., 2022) for example, improving fire detection systems, supporting research into fire-resistant landscapes, pre-season preparation and fuel management, and enhancing rapid-response capabilities. This will require dedicated, long-term investment.

Although the Perturbed Physics Ensemble (PPE) of HadCM3C captures some uncertainty in future fire weather projections by systematically perturbing key model parameters, it does not encompass the full range of outcomes across structurally different climate models. However, the structured nature of the PPE provides key advantages: it allows for a more systematic exploration of parameter-driven uncertainties and offers a more straightforward coupling between model outputs and fire weather indices like the FFDI. Unlike the CMIP multi-model ensemble, which relies on a smaller selection of available models with varying levels of evaluation for fire weather projections, the PPE is based on a single, extensively evaluated climate model. This structured approach helps isolate climate sensitivities relevant to fire risk, which would be harder to disentangle in the more heterogeneous CMIP ensemble.

Future studies incorporating a broader range of climate models could improve confidence in projections by sampling a wider range of plausible uncertainties, offering more realistic estimates of the likelihood of fire-related impacts. In particular, expanding beyond a single-model PPE could help refine fire risk estimates in regions where fire dynamics are less well understood. For example, boreal forests would benefit from research that incorporates fire indices better suited to high-latitude ecosystems, such as the Canadian Fire Weather Index (FWI), where the FFDI may be less effective. However, FFDI is a very useful metric for our temperate and tropical focus regions in this study.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

As climate models continue to improve in resolution, future assessments could further refine these projections, linking fire management needs to more specific changes in fire weather across multiple GWLs. Additionally, improving our understanding of meteorological drivers behind regionally tailored fire indices could support more targeted fire management strategies, such as early warning systems. Further research could continue to expand our findings and provide useful information for fire managers and responders. In particular, the following areas would benefit from future studies;

1. Exploring if and when fire weather might reach a point where fire suppression efforts are no longer effective once there is an ignition i.e. what are the limits of fire suppression capabilities?
2. Which policies are most effective for the projected fire weather future?
3. Developing a deeper and more nuanced understanding of ignition sources and representation of them in fire and climate models
4. Integration of socio-economic factors: Investigating how socio-economic changes, such as population growth, land-use changes, and resource availability, interact with projected fire weather to influence fire risks and management outcomes.
5. Adapting fuel load management strategies: Understanding how changes in controlled burn seasons, influenced by fire weather projections, can be optimised for fuel management while minimising unintended consequences.

5 Conclusions

This study demonstrates the profound impact of future climate change on fire weather and emphasizes the importance of both mitigation and adaptation strategies. As global temperatures rise, regions such as Australia, Brazil, and the USA are projected to face longer, earlier, and more intense fire seasons, with Very High fire weather days increasing in frequency and duration. Limiting global warming to 1.5°C could slow the rate of these changes, but even under strong mitigation scenarios, fire weather is expected to intensify, underscoring the need for adaptive measures. Fire management strategies must evolve to address shifts in fire season timing and severity, requiring expanded controlled burn windows, enhanced pre-fire preparations, and landscape management tailored to regional conditions. Ecosystem restoration through reforestation and sustainable land use can help maintain a higher soil moisture, which can reduce an ecosystems susceptibility to fire and have a favourable impact on biodiversity. An increased resilience to fire impacts for the most affected regions could be gained by considering these ecosystem services and considering fire management alongside the needs of local communities. Proactive adaptation, coupled with the development of fire weather indices suited to diverse ecosystems, will be essential for managing escalating risks. Ultimately, balancing mitigation to limit long-term impacts with adaptive measures, including ecosystem restoration, offers the greatest potential for protecting biodiversity, infrastructure, and communities in a warming world.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Code availability

The code to produce FFDI variables from HadCM3 is available at https://code.metoffice.gov.uk/trac/utils/wiki/fire, with access to Met Office Science Repository Service freely available by registering at http://jules-lsm.github.io/access_req/JULES_access.html.
The code for performing analysis and producing figures and tables is available at doi:10.5281/zenodo.14871362 (Taylor et al., 2025a)

Data availability

HadCM3 PPE FFDI outputs are available at doi:10.5281/zenodo.14860331 (Taylor et al., 2025b) for RCP2.6 and doi:10.5281/zenodo.14859064 (Taylor et al., 2025c) for RCP8.5.

Author Contributions

Inika Taylor planned and led the research, analysis and visualisation of results, with input to the experimental design and GWLs analysis framework by Richard Betts and Chantelle Burton. Inika Taylor, Douglas Kelley and Camilla Mathison conducted the analysis and visualisation of results. Andrew J. Hartley analysed and visualised the assessment of the FFDI variables. Karina Williams developed the original model code for calculating the FFDI. Inika Taylor and Douglas Kelley prepared the manuscript with contributions from Camilla Mathison, Karina Williams, Andy Hartley, Richard Betts and Chantelle Burton. Camilla Mathison reviewed and edited the draft and final manuscripts.

Competing interests

The authors declare that they have no conflict of interest.

Acknowledgements

We extend our sincere gratitude to Camilla Mathison for her exceptional dedication in coordinating co-authors and driving the manuscript forward. Her proactive efforts and commitment were instrumental in preparing this paper for submission.

We acknowledge the use of GrammarlyGO (www.grammarly.com) and ChatGPT-4 (https://chatgpt.com/) to identify improvements in language use and writing style only.

Financial support

This work and its contributors (Inika Taylor, Andy Hartley, Richard Betts, Chantelle Burton, Camilla Mathison and Karina Williams) were funded by the Met Office Hadley Centre Climate Programme (MOHCCP) and the Climate Science for Service Partnership (CSSP) Brazil project, both of which are supported by the Department for Science, Innovation & Technology (DSIT).

Douglas I. Kelley was supported by the Natural Environment Research Council as part of the LTSM2 TerraFIRMA project.

References

Abatzoglou, J. T. and Williams, A. P.: Impact of anthropogenic climate change on wildfire across western US forests, Proc. Natl. Acad. Sci. U. S. A., 113, 11770–11775, https://doi.org/10.1073/pnas.1607171113, 2016.

Abatzoglou, J. T., Williams, A. P., and Barbero, R.: Global emergence of anthropogenic climate change in fire weather indices, Geophys. Res. Lett., 46, 326–336, https://doi.org/10.1029/2018gl080959, 2019.

Anderson, L. O., Burton, C., dos Reis, J. B. C., Pessôa, A. C. M., Bett, P., Carvalho, N. S., Junior, C. H. L. S., Williams, K., Selaya, G., Armenteras, D., Bilbao, B. A., Xaud, H. A. M., Rivera-Lombardi, R., Ferreira, J., Aragão, L. E. O. C., Jones, C. D., and Wiltshire, A. J.: An alert system for Seasonal Fire probability forecast for South American Protected Areas, Climate Resilience, 1, https://doi.org/10.1002/cli2.19, 2022.

Barbosa, M. L. F., Haddad, I., and Anderson, L. O.: Time to improve disaster preparedness in Brazil, Science, 377, 1392, https://doi.org/10.1126/science.ade6396, 2022.

Best, M. J., Pryor, M., Clark, D. B., Rooney, G. G., R L, Ménard, C. B., Edwards, J. M., Hendry, M. A., Porson, A., Gedney, N., Mercado, L. M., Sitch, S., Blyth, E., Boucher, O., Cox, P. M., Grimmond, C. S. B., and Harding, R. J.: The Joint UK Land Environment Simulator (JULES), model description – Part 1: Energy and water fluxes, https://doi.org/10.5194/gmd-4-677-2011, 2011.

Bett, P. E., Williams, K. E., Burton, C., Scaife, A. A., Wiltshire, A. J., and Gilham, R.: Skillful seasonal prediction of key carbon cycle components: NPP and fire risk, Environ. Res. Commun., 2, 055002, https://doi.org/10.1088/2515-7620/ab8b29, 2020.

Betts, R. A., Cox, P. M., Collins, M., Harris, P. P., Huntingford, C., and Jones, C. D.: The role of ecosystem-atmosphere interactions in simulated Amazonian precipitation decrease and forest dieback under global climate warming, Theor. Appl. Climatol., 78, https://doi.org/10.1007/s00704-004-0050-y, 2004.

Betts, R. A., Golding, N., Gonzalez, P., Gornall, J., Kahana, R., Kay, G., Mitchell, L., and Wiltshire, A.: Climate and land use change impacts on global terrestrial ecosystems and river flows in the HadGEM2-ES Earth system model using the representative concentration pathways, Biogeosciences, 12, 1317–1338, https://doi.org/10.5194/bg-12-1317-2015, 2015.

Betts, R. A., Belcher, S. E., Hermanson, L., Klein Tank, A., Lowe, J. A., Jones, C. D., Morice, C. P., Rayner, N. A., Scaife, A. A., and Stott, P. A.: Approaching 1.5 °C: how will we know we've reached this crucial warming mark?, Nature, 624, 33–35, https://doi.org/10.1038/d41586-023-03775-z, 2023.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Blackford, K. R., Kasoar, M., Burton, C., Burke, E., Prentice, I. C., and Voulgarakis, A.: INFERNO-peat v1. 0.0: a representation of northern high-latitude peat fires in the JULES-INFERNO global fire model, Geoscientific Model Development, 17, 3063–3079, 2024.

Boer, M. M., de Dios, V. R., and Bradstock, R. A.: Unprecedented burn area of Australian mega forest fires, Nat. Clim. Chang., 10, 171–172, https://doi.org/10.1038/s41558-020-0716-1, 2020.

Booth, B. B. B., Bernie, D., McNeall, D., Hawkins, E., Caesar, J., Boulton, C., Friedlingstein, P., and Sexton, D. M. H.: Scenario and modelling uncertainty in global mean temperature change derived from emission-driven global climate models, Earth Syst. Dyn., 4, 95–108, https://doi.org/10.5194/esd-4-95-2013, 2013.

Boulton, C. A., Booth, B. B. B., and Good, P.: Exploring uncertainty of Amazon dieback in a perturbed parameter Earth system ensemble, Glob. Chang. Biol., 23, 5032–5044, https://doi.org/10.1111/gcb.13733, 2017.

Burrows, N. and McCaw, L.: Prescribed burning in southwestern Australian forests, Front. Ecol. Environ., 11, e25–e34, https://doi.org/10.1890/120356, 2013.

Burton, C., Betts, R. A., and Jones, C. D.: Will fire danger be reduced by using Solar Radiation Management to limit global warming to 1.5 C compared to 2.0 C?, Geophys. Res. Lett., 2018.

Burton, C., Betts, R. A., Jones, C. D., Feldpausch, T. R., Cardoso, M., and Anderson, L. O.: El Niño Driven Changes in Global Fire 2015/16, Front Earth Sci. Chin., 8, https://doi.org/10.3389/feart.2020.00199, 2020.

Burton, C., Lampe, S., Kelley, D. I., Thiery, W., Hantson, S., Christidis, N., Gudmundsson, L., Forrest, M., Burke, E., Chang, J., and Others: Global burned area increasingly explained by climate change, Nat. Clim. Chang., https://doi.org/10.1038/s41558-024-02140-w, 2024a.

Burton, C. A., Kelley, D., Jones, C., Betts, R., Cardoso, M., and Anderson, L.: South American fires and their impacts on ecosystems increase with continued emissions, Clim Resil Sustain, https://doi.org/10.1002/CLI2.8, 2021.

Burton, C. A., Kelley, D. I., Burke, E., Mathison, C., Jones, C. D., Betts, R. A., Robertson, E., Teixeira, J. C. M., Cardoso, M., and Anderson, L. O.: Fire weakens land carbon sinks before 1.5 °C, Nat. Geosci., 1–7, https://doi.org/10.1038/s41561-024-01554-7, 2024b.

Cirulis, B., Clarke, H., Boer, M., Penman, T., Price, O., and Bradstock, R.: Quantification of inter-regional differences in risk mitigation from prescribed burning across multiple management values, Int. J. Wildland Fire, 29, 414, https://doi.org/10.1071/wf18135, 2020.

Clarke, H. and Evans, J. P.: Exploring the future change space for fire weather in southeast Australia, Theor. Appl. Climatol., 136, 513–527, https://doi.org/10.1007/s00704-018-2507-4, 2019.

Clarke, H., Tran, B., Boer, M. M., Price, O., Kenny, B., and Bradstock, R.: Climate change effects on the frequency, seasonality and interannual variability of suitable prescribed burning weather conditions in south-eastern Australia, Agric. For. Meteorol., 271, 148–157, https://doi.org/10.1016/j.agrformet.2019.03.005, 2019.

CMES: Fire danger indices historical data from the Copernicus Emergency Management Service, https://doi.org/10.24381/CDS.0E89C522, 2019.

Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A., and Totterdell, I. J.: Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model, Nature, 408, 184–187, https://doi.org/10.1038/35041539, 2000.

De Groot, W. J., Goldammer, J. G., Justice, C. O., and Lynham, T. J.: Implementing a global early warning system for wildland fire, Proc. Virchow. Pirquet. Med. Soc., 2010.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Prescribed burning frequently asked questions: https://www.environment.sa.gov.au/topics/fire-management/prescribed-burns/prescribed-burning-faqs, last access: 2 December 2024.

Doley, R. M., Bell, R., and Watt, B. D.: An investigation into the relationship between long-term posttraumatic stress disorder symptoms and coping in Australian volunteer firefighters, J. Nerv. Ment. Dis., 204, 530–536, https://doi.org/10.1097/NMD.0000000000000525, 2016.

Dowdy, A., Mills, G., Finkele, K., and Groot, W. D.: Australian fire weather as represented by the McArthur Forest Fire Danger Index and the Canadian Forest Fire Weather Index, 2009.

Dowdy, A. J.: Climatological variability of fire weather in Australia, J. Appl. Meteorol. Climatol., 57, 221–234, https://doi.org/10.1175/jamc-d-17-0167.1, 2018.

Dowdy, A. J., Mills, G. A., Finkele, K., and de Groot, W.: Index sensitivity analysis applied to the Canadian forest fire weather index and the McArthur forest fire danger index, Meteorol. Appl., 17, 298–312, https://doi.org/10.1002/met.170, 2010.

Ferreira Barbosa, M. L., Delgado, R. C., Forsad de Andrade, C., Teodoro, P. E., Silva Junior, C. A., Wanderley, H. S., and Capristo-Silva, G. F.: Recent trends in the fire dynamics in Brazilian Legal Amazon: Interaction between the ENSO phenomenon, climate and land use, Environ. Dev., 39, 100648, https://doi.org/10.1016/j.envdev.2021.100648, 2021.

Ferreira Barbosa, M. L., Haddad, I., da Silva Nascimento, A. L., Máximo da Silva, G., Moura da Veiga, R., Hoffmann, T. B., Rosane de Souza, A., Dalagnol, R., Susin Streher, A., Souza Pereira, F. R., Oliveira e Cruz de Aragão, L. E., Oighenstein Anderson, L., and Poulter, B.: Compound impact of land use and extreme climate on the 2020 fire record of the Brazilian Pantanal, Glob. Ecol. Biogeogr., 31, 1960–1975, https://doi.org/10.1111/geb.13563, 2022.

Ferreira Barbosa, M. L., Kelley, D. I., Burton, C. A., Ferreira, I. J. M., da Veiga, R. M., Bradley, A., Molin, P. G., and Anderson, L. O.: FLAME 1.0: a novel approach for modelling burned area in the Brazilian biomes using the Maximum Entropy concept, , https://doi.org/10.5194/egusphere-2024-1775, 2024.

Ferreira, I. J. M., Campanharo, W. A., Barbosa, M. L. F., Silva, S. S. da, Selaya, G., Aragão, L. E. O. C., and Anderson, L. O.: Assessment of fire hazard in Southwestern Amazon, Front. For. Glob. Chang., 6, https://doi.org/10.3389/ffgc.2023.1107417, 2023.

Flannigan, M. D., Wotton, B. M., Marshall, G. A., de Groot, W. J., Johnston, J., Jurko, N., and Cantin, A. S.: Fuel moisture sensitivity to temperature and precipitation: climate change implications, Clim. Change, 134, 59–71, https://doi.org/10.1007/s10584-015-1521-0, 2016.

Forkel, M., Dorigo, W., Lasslop, G., Teubner, I., Chuvieco, E., and Thonicke, K.: A data-driven approach to identify controls on global fire activity from satellite and climate observations (SOFIA V1), Geoscientific Model Development, 10, 4443–4476, 2017.

Gill, A. M., Christian, K. R., Moore, P. H. R., and Forrester, R. I.: Bushfire incidence, fire hazard and fuel reduction burning, Aust. J. Ecol., 12, 299–306, https://doi.org/10.1111/j.1442-9993.1987.tb00950.x, 1987.

Golding, N. and Betts, R.: Fire risk in Amazonia due to climate change in the HadCM3 climate model: Potential interactions with deforestation, Global Biogeochem. Cycles, 22, https://doi.org/10.1029/2007gb003166, 2008.

Good, P., Lowe, J. A., Collins, M., and Moufouma-Okia, W.: An objective tropical Atlantic sea surface temperature gradient index for studies of south Amazon dry-season climate variability and change, Philos. Trans. R. Soc. Lond. B Biol. Sci., 363, 1761–1766, https://doi.org/10.1098/rstb.2007.0024, 2008.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Gordon, C., Cooper, C., Senior, C. A., Banks, H., Gregory, J. M., Johns, T. C., Mitchell, J. F. B., and Wood, R. A.: The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments, Clim. Dyn., 16, 147–168, https://doi.org/10.1007/s003820050010, 2000.

de Groot, W. J., Wotton, B. M., and Flannigan, M. D.: Chapter 11 - Wildland Fire Danger Rating and Early Warning Systems, in: Wildfire Hazards, Risks and Disasters, edited by: Shroder, J. F. and Paton, D., Elsevier, Oxford, 207–228, https://doi.org/10.1016/B978-0-12-410434-1.00011-7, 2015.

Haas, O., Prentice, I., and Harrison, S.: Global wildfires on a changing planet, Research Square, https://doi.org/10.21203/rs.3.rs-4359943/v1, 2024.

Hamilton, D. S., Kelley, D. I., Perron, M. M. G., Llort, J., and Burton, C.: The Fire science Learning AcRoss the Earth System (FLARE) Working Group FLARE: Fire science Learning AcRoss the Earth System Igniting Progress …, cnrs.hal.science, 2024.

Hantson, S., Kelley, D. I., Arneth, A., Harrison, S. P., Archibald, S., Bachelet, D., Forrest, M., Hickler, T., Lasslop, G., Li, F., Mangeon, S., Melton, J. R., Nieradzik, L., Rabin, S. S., Colin Prentice, I., Sheehan, T., Sitch, S., Teckentrup, L., Voulgarakis, A., and Yue, C.: Quantitative assessment of fire and vegetation properties in simulations with fire-enabled vegetation models from the Fire Model Intercomparison Project, https://doi.org/10.5194/gmd-13-3299-2020, 2020.

Harris, P. P., Huntingford, C., and Cox, P. M.: Amazon Basin climate under global warming: the role of the sea surface temperature, Philos. Trans. R. Soc. Lond. B Biol. Sci., 363, 1753–1759, https://doi.org/10.1098/rstb.2007.0037, 2008.

Head, L., Adams, M., and McGregor, H. V.: Climate change and Australia, Wiley Interdisciplinary, 2014.

Higuera, P. E. and Abatzoglou, J. T.: Record-setting climate enabled the extraordinary 2020 fire season in the western United States, Glob. Chang. Biol., 27, 1–2, https://doi.org/10.1111/gcb.15388, 2021.

Hoffmann, W. A., Schroeder, W., and Jackson, R. B.: Regional feedbacks among fire, climate, and tropical deforestation, J. Geophys. Res., 108, https://doi.org/10.1029/2003jd003494, 2003.

Holgate, C. M., van Dijk, A. I. J. M., Cary, G. J., and Yebra, M.: Using alternative soil moisture estimates in the McArthur Forest Fire Danger Index, Int. J. Wildland Fire, 26, 806, https://doi.org/10.1071/wf16217, 2017.

Houghton, R. M. and Lewis, H. T.: Patterns of Indian burning in California: Ecology and ethnohistory, Ethnohistory, 20, 306, https://doi.org/10.2307/481458, 1973.

Howard, T., Burrows, N., Smith, T., Daniel, G., and McCaw, L.: A framework for prioritising prescribed burning on public land in Western Australia, Int. J. Wildland Fire, 29, 314, https://doi.org/10.1071/wf19029, 2020.

Jain, P., Barber, Q. E., Taylor, S. W., Whitman, E., Castellanos Acuna, D., Boulanger, Y., Chavardès, R. D., Chen, J., Englefield, P., Flannigan, M., Girardin, M. P., Hanes, C. C., Little, J., Morrison, K., Skakun, R. S., Thompson, D. K., Wang, X., and Parisien, M.-A.: Drivers and impacts of the record-breaking 2023 wildfire season in Canada, Nat. Commun., 15, 6764, https://doi.org/10.1038/s41467-024-51154-7, 2024.

Jolly, W. M., Cochrane, M. A., Freeborn, P. H., Holden, Z. A., Brown, T. J., Williamson, G. J., and Bowman, D. M. J. S.: Climate-induced variations in global wildfire danger from 1979 to 2013, Nat. Commun., 6, 7537, https://doi.org/10.1038/ncomms8537, 2015.

Jones, M. W., Abatzoglou, J. T., Veraverbeke, S., Andela, N., Lasslop, G., Forkel, M., Smith, A. J. P., Burton, C., Betts, R. A., van der Werf, G. R., Sitch, S., Canadell, J. G., Santín, C., Kolden, C., Doerr, S. H., and Le Quéré, C.: Global and regional trends and drivers of fire under climate change, Rev. Geophys., 60, https://doi.org/10.1029/2020rg000726, 2022.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Jones, M. W., Kelley, D. I., Burton, C. A., Di Giuseppe, F., Barbosa, M. L. F., Brambleby, E., Hartley, A. J., Lombardi, A., Mataveli, G., McNorton, J. R., Spuler, F. R., Wessel, J. B., Abatzoglou, J. T., Anderson, L. O., Andela, N., Archibald, S., Armenteras, D., Burke, E., Carmenta, R., Chuvieco, E., Clarke, H., Doerr, S. H., Fernandes, P. M., Giglio, L., Hamilton, D. S., Hantson, S., Harris, S., Jain, P., Kolden, C. A., Kurvits, T., Lampe, S., Meier, S., Stacey New, Parrington, M., Perron, M. M. G., Qu, Y., Ribeiro, N. S., Saharjo, B. H., San-Miguel-Ayanz, J., Shuman, J. K., Tanpipat, V., van der Werf, G. R., Veraverbeke, S., and Xanthopoulos, G.: State of wildfires 2023–2024, Earth Syst. Sci. Data, 16, 3601–3685, https://doi.org/10.5194/essd-16-3601-2024, 2024.

Kaye, N. R., Hartley, A., and Hemming, D.: Mapping the climate: guidance on appropriate techniques to map climate variables and their uncertainty, Geosci. Model Dev., 5, 245–256, https://doi.org/10.5194/gmd-5-245-2012, 2012.

Kelley, D. I. and Harrison, S. P.: Enhanced Australian carbon sink despite increased wildfire during the 21st century, Environ. Res. Lett., 9, 104015, https://doi.org/10.1088/1748-9326/9/10/104015, 2014.

Kelley, D. I., Bistinas, I., Whitley, R., Burton, C., Marthews, T. R., and Dong, N.: How contemporary bioclimatic and human controls change global fire regimes, Nat. Clim. Chang., 9, 690–696, https://doi.org/10.1038/s41558-019-0540-7, 2019.

Kelley, D. I., Burton, C., Huntingford, C., Brown, M. A. J., Whitley, R., and Dong, N.: Technical note: Low meteorological influence found in 2019 Amazonia fires, Biogeosciences, 18, 787–804, https://doi.org/10.5194/bg-18-787-2021, 2021.

Kloster, S. and Lasslop, G.: Historical and future fire occurrence (1850 to 2100) simulated in CMIP5 Earth System Models, Glob. Planet. Change, 150, 58–69, https://doi.org/10.1016/j.gloplacha.2016.12.017, 2017.

Knapp, E. E., Estes, B. L., and Skinner, C. N.: Ecological Effects of Prescribed Fire Season: A Literature Review and Synthesis for Managers, 2009.

Lambert, F. H., Harris, G. R., Collins, M., Murphy, J. M., Sexton, D. M. H., and Booth, B. B. B.: Interactions between perturbations to different Earth system components simulated by a fully-coupled climate model, Clim. Dyn., 41, 3055–3072, https://doi.org/10.1007/s00382-012-1618-3, 2013.

Levine, B., Hemer, S., Denman, T., and Farquhar, S.: Prescribed burn decision support tool (PB DST): An essential process to support your decisionmaking, In: Hood, Sharon M.; Drury, Stacy; Steelman, Toddi; Steffens, Ron,[eds.]. Proceedings of the Fire Continuum-Preparing for the future of wildland fire; 2018 May 21-24; Missoula, MT. Proceedings RMRS-P-78. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 168-176, 78, 168–176, 2020.

Masson-Delmotte, V. P., Zhai, P., Pirani, S. L., Connors, C., Pean, S., Berger, N., Caud, Y., Chen, L., Goldfarb, M. I., and Scheel Monteiro, P. M.: Ipcc, 2021: Summary for policymakers. in: Climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the …, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2021.

Mataveli, G., de Oliveira, G., Silva-Junior, C. H. L., Stark, S. C., Carvalho, N., Anderson, L. O., Gatti, L. V., and Aragão, L. E. O. C.: Record-breaking fires in the Brazilian Amazon associated with uncontrolled deforestation, Nat. Ecol. Evol., 6, 1792–1793, https://doi.org/10.1038/s41559-022-01945-2, 2022.

Mataveli, G., Jones, M. W., Carmenta, R., Sanchez, A., Dutra, D. J., Chaves, M., de Oliveira, G., Anderson, L. O., and Aragão, L. E. O. C.: Deforestation falls but rise of wildfires continues degrading Brazilian Amazon forests, Glob. Chang. Biol., 30, e17202, https://doi.org/10.1111/gcb.17202, 2024.

Morgan, G. W., Tolhurst, K. G., Poynter, M. W., Cooper, N., McGuffog, T., Ryan, R., Wouters, M. A., Stephens, N., Black, P., Sheehan, D., Leeson, P., Whight, S., and Davey, S. M.: Prescribed burning in south-eastern Australia: history and future directions, Aust. For., 83, 4–28, https://doi.org/10.1080/00049158.2020.1739883, 2020.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Noble, I. R., Gill, A. M., and Bary, G. A. V.: McArthur's fire-danger meters expressed as equations, Aust. J. Ecol., 5, 201–203, https://doi.org/10.1111/j.1442-9993.1980.tb01243.x, 1980.

O'Brien, P. and Campbell, D.: Wildland firefighter psychological and behavioral health: preliminary data from a national sample of current and former wildland firefighters in the United States, in: Proceedings of the International Association of Wildland Fire 6th Annual Human Dimensions Conference, 2021, 2021.

van Oldenborgh, G. J., Krikken, F., Lewis, S., Leach, N. J., Lehner, F., Saunders, K. R., van Weele, M., Haustein, K., Li, S., Wallom, D., Sparrow, S., Arrighi, J., Singh, R. P., van Aalst, M. K., Philip, S. Y., Vautard, R., and Otto, F. E. L.: Attribution of the Australian bushfire risk to anthropogenic climate change, Natural Hazards and Earth System Sciences Discussions, https://doi.org/10.5194/nhess-2020-69, 2020.

Pandey, P., Huidobro, G., Lopes, L. F., Ganteaume, A., Ascoli, D., Colaco, C., Xanthopoulos, G., Giannaros, T. M., Gazzard, R., Boustras, G., Steelman, T., Charlton, V., Ferguson, E., Kirschner, J., Little, K., Stoof, C., Nikolakis, W., Fernández-Blanco, C. R., Ribotta, C., Lambrechts, H., Fernandez, M., and Dossi, S.: A global outlook on increasing wildfire risk: Current policy situation and future pathways, Trees For. People, 14, 100431, https://doi.org/10.1016/j.tfp.2023.100431, 2023.

Russell-Smith, J., McCaw, L., and Leavesley, A.: Adaptive prescribed burning in Australia for the early 21st Century – context, status, challenges, Int. J. Wildland Fire, 29, 305, https://doi.org/10.1071/wf20027, 2020.

Santos, F. L. M., Nogueira, J., Souza, R. A. F. de, Falleiro, R. M., Schmidt, I. B., and Libonati, R.: Prescribed burning reduces large, high-intensity wildfires and emissions in the Brazilian Savanna, Fire, 4, 56, https://doi.org/10.3390/fire4030056, 2021.

Schmidt, I. B., Moura, L. C., Ferreira, M. C., Eloy, L., Sampaio, A. B., Dias, P. A., and Berlinck, C. N.: Fire management in the Brazilian savanna: First steps and the way forward, J. Appl. Ecol., 55, 2094–2101, https://doi.org/10.1111/1365-2664.13118, 2018.

Sharples, J. J., Cary, G. J., Fox-Hughes, P., Mooney, S., Evans, J. P., Fletcher, M.-S., Fromm, M., Grierson, P. F., McRae, R., and Baker, P.: Natural hazards in Australia: extreme bushfire, Clim. Change, 139, 85–99, https://doi.org/10.1007/s10584-016-1811-1, 2016.

Silveira, M. V. F., Petri, C. A., Broggio, I. S., Chagas, G. O., Macul, M. S., Leite, C. C. S. S., Ferrari, E. M. M., Amim, C. G. V., Freitas, A. L. R., Motta, A. Z. V., Carvalho, L. M. E., Silva Junior, C. H. L., Anderson, L. O., and Aragão, L. E. O. C.: Drivers of Fire Anomalies in the Brazilian Amazon: Lessons Learned from the 2019 Fire Crisis, Land, 9, 516, https://doi.org/10.3390/land9120516, 2020.

Sirakoff, C.: A correction to the equations describing the McArthur forest fire danger meter, Aust. J. Ecol., 10, 481–481, https://doi.org/10.1111/j.1442-9993.1985.tb00909.x, 1985.

Stephens, S. L., McIver, J. D., Boerner, R. E. J., Fettig, C. J., Fontaine, J. B., Hartsough, B. R., Kennedy, P. L., and Schwilk, D. W.: The effects of forest fuel-reduction treatments in the United States, Bioscience, 62, 549–560, https://doi.org/10.1525/bio.2012.62.6.6, 2012.

Taylor, I., Williams, K., Mathison, C., Kelley, D., Hartley, A., Betts, R., and Burton, C.: Analysis code for Limiting global warming to 1.5°C minimises projected global increases in fire weather days, but adaptation to new fire regimes is still needed, Zenodo, https://doi.org/10.5281/zenodo.14871362, 2025a.

Taylor, I., Williams, K., Mathison, C., Hartley, A., Betts, R., Kelley, D., and Burton, C.: Global Daily FFDI Projections from HadCM3C Perturbed Physics Ensemble - RCP2.6, https://doi.org/10.5281/zenodo.14860331, 2025b.

https://doi.org/10.5194/egusphere-2025-720
Preprint. Discussion started: 24 March 2025

Taylor, I., Williams, K., Mathison, C., Hartley, A., Betts, R., Kelley, D., and Burton, C.: Global Daily FFDI Projections from HadCM3C Perturbed Physics Ensemble - RCP8.5, https://doi.org/10.5281/zenodo.14859064, 2025c.

Taylor, I. H., Burke, E., McColl, L., Falloon, P. D., Harris, G. R., and McNeall, D.: The impact of climate mitigation on projections of future drought, Hydrol. Earth Syst. Sci., 17, 2339–2358, https://doi.org/10.5194/hess-17-2339-2013, 2013.

Udy, D. G., Vance, T. R., Kiem, A. S., Holbrook, N. J., and Abram, N.: Australia’s 2019/20 Black Summer fire weather exceptionally rare over the last 2000 years, Commun. Earth Environ., 5, 1–13, https://doi.org/10.1038/s43247-024-01470-z, 2024.

UNEP, Popescu, A., Paulson, A. K., Christianson, A. C., Sullivan, A., Tulloch, A., Bilbao, B., Mathison, C., Robinson, C., Burton, C., Ganz, D., Nangoma, D., Saah, D., Armenteras, D., Driscoll, D., Hankins, D. L., Kelley, D. I., Langer, E. R. L., Baker, E., Berenguer, E., Reisen, F., Robinne, F.-N., Galudra, G., Humphrey, G., Safford, H., Baird, I. G., Oliveras, I., Littell, J., Kieft, J., Chew, J., Maclean, K., Wittenberg, L., Anderson, L. O., Gillson, L., Plucinski, M., Moritz, M., Brown, M., Soto, M. C., Flannigan, M., Costello, O., Silva, P. S., Fernandes, P., Moore, P., Jandt, R., Blanchi, R., Libonati, R., Archibald, S., Dunlop, S., McCaffrey, S., Page, S., Gonzãƒâ¡lez, T. D. T., Sokchea, T., and Charlton, V.: Spreading like Wildfire: The Rising Threat of Extraordinary Landscape Fires, edited by: Sullivan, A., Kurvits, T., and E., B., United Nations Environment Programme and GRID-Arendal., 2022.

UNFCCC: Adoption of the Paris agreement, 21st conference of the parties, 2015.

da Veiga, R. M. and Nikolakis, W.: Fire management and carbon programs: A systematic literature review and case study analysis, Soc. Nat. Resour., 35, 896–913, https://doi.org/10.1080/08941920.2022.2053618, 2022.

da Veiga, R. M., von Randow, C., Burton, C., Kelley, D., Cardoso, M., and Morelli, F.: Review article: Understanding the placement of fire emissions from the Brazilian Cerrado biome in the atmospheric carbon budget, , https://doi.org/10.5194/egusphere-2024-2348, 2024.

Volpato, M., Andrade, C. F., Silva, E. L., Barbosa, M. L., Andrade, M. D., Rocha, P. V., Delgado, R. C., Teodoro, P. E., Silva, C. A., and Pereira, M. G.: Fire foci and their spatiotemporal relations to weather variables and land uses in the state of Mato Grosso, Environ. Dev. Sustain., 25, 12419–12438, https://doi.org/10.1007/s10668-022-02573-3, 2023.

Ward, M., Tulloch, A. I. T., Radford, J. Q., Williams, B. A., Reside, A. E., Macdonald, S. L., Mayfield, H. J., Maron, M., Possingham, H. P., Vine, S. J., O’Connor, J. L., Massingham, E. J., Greenville, A. C., Woinarski, J. C. Z., Garnett, S. T., Lintermans, M., Scheele, B. C., Carwardine, J., Nimmo, D. G., Lindenmayer, D. B., Kooyman, R. M., Simmonds, J. S., Sonter, L. J., and Watson, J. E. M.: Impact of 2019–2020 mega-fires on Australian fauna habitat, Nature Ecology & Evolution, 4, 1321–1326, https://doi.org/10.1038/s41559-020-1251-1, 2020.

Williams, A. P., Abatzoglou, J. T., Gershunov, A., Guzman-Morales, J., Bishop, D. A., Balch, J. K., and Lettenmaier, D. P.: Observed impacts of anthropogenic climate change on wildfire in California, Earths Future, 7, 892–910, https://doi.org/10.1029/2019ef001210, 2019.

Yeo, C. S., Kepert, J. D., and Hicks, R.: Fire danger indices: current limitations and a pathway to better indices, Bushfire & Natural Hazards CRC, Melbourne, Victoria, Australia, 2015.